ESTIMATION OF TIME

An experimental study

BY

MARIANNE FRANKENHAEUSER

Uppsala 1959

ALMQVIST & WIKSELL
STOCKHOLM

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FIL. LIC., VÄRML.

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INTRODUCTION

The relation between objective and subjective time has attracted interest in several branches of science as well as in philosophy. The vast majority of the studies in this field—including those by psychologists—follow a speculative, non-experimental line, but several attempts have also been made to approach the problem by experimental methods. So far, these attempts have led to contradictory results and, above all, conflicting interpretations. Part of the confusion is undoubtedly related to inadequacy of methods and ambiguity of terminology. More fundamental is perhaps the lack of a stringent theory on which to base experimental approaches. As a consequence, our knowledge of the mechanisms governing subjective time is at present very scanty and by far less comprehensive than our knowledge of psychological functioning in neighbouring fields, such as perception of space.

One major difficulty in experimental studies within this field is that time experience is influenced by a multitude of factors, some of which, e.g. emotional factors, are difficult to keep under control. Indeed the question presents itself, whether the problem of subjective time defies a strict experimental approach. No doubt, subjective time is so fascinating a theme that one may develop ideas and concepts without resorting to experimental evidence in a strict sense. However, in the present investigation the approach was based strictly on experimental principles.

Essentially, the work originated from the assumption that the experience of time is closely related to the experience, i.e. perception and retention, of other events. It was emphasized that a distinction should be made between these two processes in the experience of time as well: perception, which refers to the more

or less immediate experience of brief time intervals, and retention, which refers to the experience of time intervals in retrospect. Hence, on the basis of our knowledge of perception and retention of other processes, as studied in less complex fields, it should be possible to formulate hypotheses concerning the experience of time which can be submitted to experimental test.

The three main problems of the present investigation are to examine (1) the relation between the time perceived and the time retained, (2) conditions influencing the perception of time and (3) conditions influencing the retention of time.

Perception of time was examined by a modification of the method of counting at an estimated speed of 1 per second. Retention of time was examined by the method of verbal estimation of an elapsed time period. The experiments were restricted to relatively short time intervals; with a few exceptions the intervals studied did not exceed 72 seconds, 53 seconds being the upper limit in most cases. In order to permit an analysis of the relation between time perceived and time retained, a special method was devised by which combined measurements of these two aspects of the time experience could be obtained. This method also allowed us to examine differentially the effects of various factors on the two types of time experience. Hence it has been possible to obtain information of the time experience which has not been provided by the methods used by previous investigators.

An attempt has been made to create experimental situations, where it would be possible to control the factors which influence the time experience. This implies that a large part of the factors which influence the experience of time under ordinary conditions of life, in particular emotional factors, have been eliminated or at least their influence has been reduced. Such a restriction is necessary in order to permit a meaningful analysis of the results.

In Part I of this report the background to the present investigation is outlined (Chapter I), the problems and hypotheses are presented (Chapter II) and a brief review of some earlier investigations is given (Chapter III).

Part II, the experimental section, starts with a description of the methods used (Chapter IV) followed by accounts of the experiments (Chapters V to IX). Chapter X contains a general discussion of problems and results and Chapter XI a general summary of the investigation.

The experimental findings showed (1) that the amount of time retained is less than the amount perceived, (2) that the perception of time is influenced by the amount of mental content per objective time unit and (3) that the retention of time varies with conditions affecting memory processes in general.

PART I

CHAPTER I

BACKGROUND TO THE PRESENT INVESTIGATION

Perception and retention of time

As yet no theory has been advanced which could adequately account for the mechanisms governing subjective time. Nichols in 1890 characterized theories of time perception in the following way: "Casting an eye backward we can but be struck by the wide variety of explanations offered for the time-mystery. Time has been called an act of mind, of reason, of perception, of intuition, of sense, of memory, of will, of all possible compounds and compositions to be made up from all of them. It has been deemed a General Sense accompanying all mental content in a manner similar to that conceived of pain and pleasure. It has been assigned a separate, special, disparate sense, to nigh a dozen kinds of 'feeling', some familiar, some strangely invented for the difficulty. It has been explained by 'relations', by 'earmarks', by 'signs', by 'remnants', by 'struggles' and by 'strifes', by 'luminous trains', by 'blocks of specious-present', by 'apperception'. It has been declared *a priori*, innate, intuitive, empirical, mechanical. It has been deduced from within and from without, from heaven, and from earth, and from several things difficult to imagine as of either."

This description is more or less applicable to the present status of theories of time perception. No serious attempt seems to have been made to relate theories in this field to psychological theories in other fields. Nor is it immediately obvious to which area of psychological functioning the time experience belongs. We will use the word "experience" in an attempt to cover the

various psychological processes which belong to the realm of subjective or psychological time. An inspection of the processes generally referred to under the heading "time perception" makes it clear that this term is used to cover estimates of both immediately perceived, brief time intervals and of longer time periods regarded in retrospect. This is confusing, since generally in psychology the term perception is used exclusively to denote the mental process elicited by a more or less simultaneously present stimulus, whereas the mental processes related to previously perceived stimuli are referred to as memory processes. Thus perception refers to an immediate sensory response of the organism, whereas responses affected by the ability of the organism to *retain* fall within the realm of memory.

Consequently the term perception of time should be restricted to the subjective experience of relatively brief intervals, i.e. intervals falling within the "conscious present". The concept of the conscious present (also called specious present, mental present, Präsenzzeit and subjective now) has been subject of considerable debate (e.g. Boring, 1936). Measurements of the conscious present are generally carried out by determining the length of the time period over which stimuli may be spread and yet conceived as one temporal unit. The size ascribed to the conscious present varies considerably from one study to another, a fact which is certainly related to the vague definition of the concept. Boring (1933, p. 135) concludes that "the proper generalization seems to be that the conscious present can certainly include a rhythmical grouping that occupies a second or a second and a half, and that with somewhat less 'immediacy' a consciousness may extend to include a rhythm of a quarter or perhaps even half a minute". Piéron (1952, p. 292) describes the conscious present as "compatible with a certain perceptive unification. Up to a certain limit of time, a series of successive events can be retained—like water in the hollow of the hand, as it were—in an act of unified comprehension. This limit is generally placed at 5 or 6 seconds, with some variability from one individual to another." Fraisse (1957, pp. 89–91) points out that the length of the conscious present varies with the characteristics of the

stimulus content: the length of the interval between stimuli, the number of separate stimuli and the grouping of stimuli.

It is not necessary for the purpose of the present investigation to delimit strictly the duration of the conscious present. But it is important to realize the differences in the mental processes which underlie the estimation of brief time intervals, which are more or less directly perceived, and the estimation of longer time intervals which are retained in memory.

Experience of time as a function of other processes

Among the manifold of theories of subjective time which have been advanced two main views may be distinguished. One is that there exists a special time sense, a sense for "pure time". The other view holds that the experience of time is a function of other (psychological and physiological) processes.

Arguments commonly presented in support of the theory of a special time sense are the ability ascribed to some individuals to awaken at predetermined times (Brush, 1930; Clauser, 1954), the accuracy in respect of time with which post-hypnotic suggestions are carried out (e.g. Häfner, 1954), the ability to judge time fairly accurately when deprived of external cues (e.g. MacLeod & Roff, 1936), and the apparent acceleration and deceleration of time in some cases of brain disease, which occurs independently of the individual's ability to judge time with the aid of cognitive cues (e.g. Häfner, 1954; Spiegel *et al.*, 1955).

Of these phenomena the ability to wake up at predetermined times is probably the most striking and it certainly points to some sort of timing mechanism which operates independently of conscious cues. It appears, however, that such an ability, if it exists, is not common for all individuals. Neither is the existence of this ability necessarily contradictory to the assumption that the experience of time is based on perceptions mediated through other senses, though it seems to eliminate the necessity of a *conscious evaluation* of these processes. Anyhow, none of the above-mentioned phenomena lend decisive support to the theory

of a special time sense—"a sense to which empty duration is an adequate stimulus" as James (1890, p. 619) expresses it when debating this view. He also points to the analogy to space perception: ". . . we can no more intuite a duration than we can intuite an extension, devoid of all sensible content" (*op. cit.*, p. 620).

In this investigation we will conform to the general theory adopted by the majority of investigators in this field according to which the experience of time is based on the perception and retention of other processes, a view summarized by James (*op. cit.*, p. 619) in the sentence "We have no sense for empty time."

We may assume that the experience of a certain duration is related to the total amount of experience (sensations, perceptions, cognitive and emotional processes, etc.) which takes place within this time period, in short, the *amount of mental content*. We may also assume that different mental processes influence the time experience in various degrees. It then remains to attempt to analyse the relation between the experience of time and these other processes on which it depends.

In spite of the rather general agreement that the time experience is closely linked to other mental processes, it has proved difficult to establish rules for this relationship and thus to predict specific changes in the time experience on the basis of changes in experimentally varied "fillings" of physical time periods. Experimental results and, in particular, interpretations of experimental data are characterized by striking contradictions. Part of this confusion is undoubtedly associated with the multiplicity of factors which influence the time experience, some of which are difficult to control, particularly factors of an emotional nature. The abstract nature of the time experience, i.e. the lack of concrete and well-defined external standards as provided in other fields of perception, makes it extremely susceptible to a large number of divergent influences.

It is well known from everyday experience that the seeming duration of a time period of one and the same objective length may vary considerably; indeed, this variability is one of the striking characteristics of subjective time. On the whole, time

seems shorter when filled with interesting, pleasant or amusing activities than when spent in boredom, anxiety or discomfort. The general rule seems to be that time seems long when the attention is directed towards the passage of time, i.e. when the individual's attitude is characterized by anticipation, whereas the less attention is given to time itself, the more rapidly it seems to flow. Indeed, the influence of attitudinal and motivational factors is so strong that these, if present, might easily obscure, or even distort, effects of experimental variables of a non-emotional nature.

These considerations point to the conclusion that out of the various processes which constitute the mental content, emotional factors are possibly those with the strongest influence on the time experience. The emotional factors are likewise usually the factors which are most difficult to keep under experimental control. Thus the situation easily arises in which it cannot be determined whether changes in time judgment in a certain situation are caused by variations in experimental variables or by emotional factors which occupy the subject's mental content at the time of the measurement. In short, we may not have the situation under control so as to be able to state that the response obtained is made to the experimental stimulus rather than to other simultaneous but uncontrolled stimuli. These experimental problems, though far from unique for measurement of subjective time, are likely to be especially pronounced and difficult to avoid in this particular field.

It is thus evident that in order to permit testing of experimental hypotheses concerning subjective time, a situation has to be arranged where the mental content of the subject is principally determined and controlled by the experimentally induced filling of a time period. This, in turn, implies that (as long as we are not concerned with the effects of one particular emotional factor) the experimental filling should be as far as possible neutral, devoid of elements of an emotional nature. At the same time, it is obvious that a rigid control of the experimental situation will deprive it of many of the elements which in actual life have the strongest influence on the experience of time. Results obtained

under laboratory conditions may therefore be limited in terms of direct practical applicability, but will provide material for theory which could otherwise not be had.

Methodological considerations

Measurement of subjective time differs from measurements commonly made in other fields of psychophysics in certain important respects. An outstanding characteristic of the time judgment is that it cannot be based on a comparison with more or less simultaneous external standards. In respect of present time the judgment is based on an internal standard, whereas estimates of past time are based on the retention of the perception of a preceding standard.

Measurement of present time.—The term "present-time estimate" will be used to denote a judgment based on a more or less immediate perception of short time intervals. Such estimates may be expected to be relatively unaffected by memory factors. When estimates of present time are obtained by asking the subject to count at a subjective rate of 1 per second, he bases his estimate on an internal standard, i.e. a standard built into the organism by a process of over-learning. This learning process may be described as learning to assess the amount of mental content which (on an average) corresponds to 1 physical second.

Measurement of past time.—The term "past-time estimate" will be used to denote the retrospective estimate of a time period which has just elapsed. In this case the estimate will be based on the memory of the perception of the preceding stimulus duration delimited by the experimenter. Thus memory factors may be expected to play a predominant role in the estimate.

From a technical point of view measurement of subjective past time resembles measurements obtained in other fields of psychophysics by comparison of successive stimuli, where so-called

time-order errors are known to affect the judgment. The specific implication of the time-order error in respect of time experience will be considered later (p. 20).

In certain respects measurement of subjective time resembles measurement of learning. What we measure in a learning experiment is the retention of a preceding acquisition of stimulus–response connections. Similarly, what we measure in experiments on subjective past time is the retention of the preceding perception of a stimulus duration. It should be pointed out that we shall use the term *retention* of time in an operational sense to indicate the combined effects of various memory processes on retrospective estimates of previously perceived time. The distinction — important in learning theory — between acquisition and retention (of what was previously acquired) is not necessarily relevant in this connection. Our main distinction is between perception and retention (of what was previously perceived). What may be directly measured in experiments on retrospective time estimation as well as in learning experiments is retention in this operational sense.

However, the differences between retention in experiments on learning and on subjective time are obvious. Learning is usually measured by the number of items *correctly* retained, whereas in measurement of subjective time we are only concerned with the *amount* perceived and retained. The question of a correct retention of specific details in the material presented, which is the outstanding characteristic of the learning process, thus has little, if any relevance for the experience of duration, where emphasis is solely on amount retained. (The correct retention of details enters into the problems of *temporal localization*, a special aspect of subjective time with which we are not concerned here.) Furthermore, one of the principal characteristics of the learning process is the effect of repetition on retention, whereas in respect of the time experience repetition is inherently excluded. Yet another difference is that the experience of time in retrospect generally does not involve the feeling of something "being lost", as is the case in retention of learned material. The analogy between retention in experiments on learning and on

subjective time is thus restricted to the fact that what we measure is in both cases the retention of previously perceived stimuli.

Subjective time and estimated time.—Measurements of subjective time are obtained in the form of judgments or estimates, i.e. the data lie on the judgment continuum as distinct from the subjective continuum which must be inferred from the former (cf. Guilford, 1954, pp. 29–30). In respect of subjective time there is plenty of reason to expect a considerable discrepancy between the two continua. Because time estimation has acquired a great social importance in civilized societies, the individual gets a considerable amount of practice in adjusting his subjective impressions to physical standards. He also learns to make allowances for such factors as experience has taught him will distort the relation between subjective och objective time. Thus, though care is taken to induce a naive attitude in the subject, it is nevertheless likely that he will attempt to correct his estimate on the basis of cognitive cues. These corrections will remove the estimated time from the subjective time. Since we must be prepared for the fact that cues always operate to a greater or lesser extent, at least at a subconscious level, the measure obtained will constitute a compromise between the subjective experience and an intellectual estimate. Consequently, the estimated time is likely to lie between the subjective and the physical time and to indicate the tendency of the former rather than to provide a true measure of it.

The time-order error

One of the obvious consequences of the assumption that experience of time is related to the experience of other events is that the memory of time should undergo the same sort of change with increasing remoteness to the events as the memory of the events themselves. Since, on the whole, experiences are likely to be strongest when they take place and to fade in memory as time progresses, the time experiences should be subject to a similar forgetting.

The complexity of the relation between the immediate perception and the retention of events is demonstrated in the so-called time-order error. We shall therefore consider the general characteristics of this phenomenon, as well as some of the theories advanced to explain it.

Psychophysical measurements by means of successive comparison have shown that the point of subjective equality between two successively presented stimuli is usually not identical with the point of objective equality. The difference between subjective and objective equality induced by the order of presentation is designated the time-order error. When, for example, two objectively equal stimuli are compared, the first stimulus in the pair will usually seem less than the second. In this case the time-order error is *negative*, whereas when the first stimulus is judged the greater, the error is *positive*. Time-order errors occur in both directions, positive and negative, but the negative errors are by far the most common.

Köhler (1923) tried to account for the phenomenon in terms of a "*fading-trace*" theory. In essence this theory states that the neurological trace left by a sensory stimulus tends to disintegrate through time. The second stimulus in the pair will make a fresh impression which is compared with the sinking or fading trace of the first stimulus. The outcome of the comparison between the fresh and the faded trace will be a negative time-order error. This explanation obviously does not take into account the positive time-order errors. However, positive errors are typically found when the interval between the two stimuli is short and it may thus be possible to account for them in terms of a temporary decrease in the excitability of the sensory path stimulated. In Köhler's experiment on loudness positive errors occurred with intervals of 1.5 seconds; with 3-second intervals the time-order error was practically zero, whereas with longer intervals, up to 12 seconds, the error became negative and the magnitude of the error increased with increasing length of the interval.

Lauenstein (1933) extended Köhler's fading-trace explanation by introducing the concept of *assimilation*. Briefly his theory implies that the trace made by the first stimulus does not

sink or fade in a passive way but tends to assimilate with traces made by other simultaneous brain processes. Thus the direction of the time-order error would depend upon the interpolation between the two stimuli: an interpolation of high intensity would yield a positive and an interpolation of low intensity a negative error (provided that only the traces left by the *first* stimulus were affected by assimilation processes). Lauenstein presents experimental evidence in support of his theory.

This explanation in terms of assimilation has much in common with other explanations which emphasize the influence of frame of reference (e.g. Bartlett, 1939) and level of adaptation (Michels & Helson, 1954), in that they all stress the interaction between the impression of one particular stimulus and contextual factors. The experimental findings strongly favour an explanation which takes into account the dependence of the trace left by one stimulus on the general setting in which the stimulus is presented. The so-called *central tendency effect* provides a striking example of this. In an experiment where a series of stimuli of varying magnitude is employed, weak stimuli will typically yield positive and strong stimuli negative time-order errors thus indicating that the impression of the first stimulus regresses towards the average value of the stimuli perceived (cf. Osgood 1953, pp. 56–57).

Time-order errors in time experience.—Time-order errors also occur in the measurement of subjective time. Short intervals typically yield positive and long intervals negative time errors (e.g. Vierordt, 1868; Roelofs & Zeeman, 1949 *a*, *b*). The intermediate point where the time-order error is zero is called the *indifference interval*. This is more strictly defined as the point where the comparison of two successive durations is not affected by the order of presentation.

Measures of the indifference interval may also be obtained by the method of reproduction, in which case the standard will always precede the variable. The indifference interval is the point where the physical standard and the subject's reproduction are identical.

It is easily seen that the indifference interval may serve as a measure of the "conscious present" as pointed out by Boring (1933, pp. 135–136), since it refers to a time interval the estimate of which is not affected by memory factors.

Woodrow (1951) summarized the results from various studies and states that the range of indifference intervals reported extends from 0.36 to 5 seconds, intervals of 0.5 to 0.7 seconds being those most frequently reported. Inter-individual differences have been shown to be large (Woodrow, 1930). The influence of contextual factors has been clearly demonstrated in experiments showing that the size of the indifference interval varies with the range of stimuli used, in such a manner that it tends to lie in the middle of the particular stimulus series employed (Woodrow, 1935; Fraisse, 1948).

Thus it seems that time-order errors, as found in the measurement of subjective time, have the same general characteristics as in other fields of psychophysical measurement. The fact that impression of time undergoes similar changes as impressions of other psychological processes agrees with the assumption that the experience of time depends upon the experience of other processes.

However, it is important to realize the totally different implication of the time-order error in respect of the time experience as compared with time errors as found in other fields. The term "error" refers to the fact that the judgment is distorted because of the temporal succession of stimuli. Such errors may be counterbalanced by rotation and the influence of succession thus eliminated. In respect of subjective time, however, *succession is in itself an inherent characteristic of the experience.* Thus the discrepancy between immediate perception and retention of time is not an error caused by methodological inadequacies which we want to eliminate, but rather a typical expression of the phenomenon we want to study.

CHAPTER II

PROBLEMS AND HYPOTHESES

The relation between present and past time

The problems of the present investigation will now be discussed in the light of the above considerations and experimental hypotheses will be put forward.

The first problem concerns the relation between time perceived and time retained. We assume that the experience of time is related to the experience of other events, the mental content, and that the difference between time perceived and retained will be analogous to the difference between the perception and retention of the events which constitute the mental content.

One of the characteristic alterations which impressions undergo when the stimulus is removed from inspection is that of fading: the content of the memory of a perception is less than the content of the perception itself. Although, as described above, traces left by other simultaneous brain processes may interfere with the fading and induce other changes, these effects may be decreased as the number of simultaneous brain processes is decreased. In a situation where the mental content consists essentially of the perception of one type of sensory stimulus, the change in brain traces would consist essentially of fading. Similarly, the time experience attached to these impressions would be characterized by fading.

In order to examine the relation between time perceived and retained we have to obtain separate measures of the perception and retention of one and the same time period. Experiments

carried out by previous investigators have been restricted to the measurement of one of these two aspects at a time. Estimates of present time have been compared with objective time and, likewise, estimated past time has been related to objective time. No previous attempt seems to have been made to relate these two types of time estimates directly to each other.

The first hypothesis may be formulated as follows:

Hypothesis I: The relation between time perceived and time retained is analogous to the relation between the perception and retention of the mental events on which the time experience is based. Because amount retained is usually less than amount perceived, the estimate of a past-time interval will be smaller than the sum of the successive present-time estimates on which it is based.

Conditions affecting present-time estimates

Our second problem concerns the factors which influence the immediate perception of brief time intervals. As stated above the expression "immediate perception of time" will be used only to denote the experience of short time intervals which may be assumed to lie within the conscious present and thus to be relatively unaffected by memory factors. The 1-second interval fulfills these requirements and also provides a convenient unit of measurement. The problem is thus restricted to the question of which factors influence the subjective duration of the objective second.

On the basis of the assumption that perception of time varies with amount of mental content we expect a change in mental content to affect the time perception. The first question which arises concerns the direction of change in time perception caused by a decrease versus an increase in amount of mental content per objective time unit.

The internal 1-second standard is formed by a process of learning. The individual has learnt to judge the approximate amount of mental content which normally corresponds to 1 objective second. If this amount is increased (without the indi-

vidual being aware of the increase and thus able to "adapt" his time estimate) it follows that the objective second should seem subjectively longer: when 1 clock second has passed, the individual's mental content will exceed the amount of mental content generally associated with 1 objective second. This implies that, when estimating seconds by counting, the subject should count at a faster rate when the amount of mental content is increased, since the subjective second now corresponds to a smaller amount of objective time. Conversely, when the amount of mental content is decreased the objective second should seem subjectively shorter and the counting should be slower.

It then remains to discuss the factors which are likely to influence the amount of mental content. These may be divided into *external* and *internal factors*.

An increase and a decrease in *external* stimulation is easily brought about by changes in the environment. The conditions under which changes in external stimulation affect the relation between the objective and subjective second will be considered in the experimental section. At present we can only state that we expect such changes in external factors as influence the amount of mental content also to influence the objective duration of the subjective second.

One way of changing the *internal* stimulation is to administer drugs known to affect the level of mental alertness. Such drugs may be expected to affect the amount of mental content by altering the speed of mental processes as well as the subject's sensitivity to external stimulation. If the amount of external stimulation remains the same and mental alertness varies, the amount perceived should be larger when the subject is more alert. Similarly, the relation between the objective and subjective second should vary with the degree of mental alertness, so that the objective second should seem subjectively longer when the degree of mental alertness is increased.

We may formulate our second hypothesis as follows:

Hypothesis II: The relation between the objective and subjective second varies with the amount of mental content. An increase in mental content will cause the objective second to

seem subjectively longer and, conversely, a decrease in the mental content will make the objective second subjectively shorter.

Conditions affecting past-time estimates

The retrospective estimate of a time interval depends partly upon the amount of time perceived during this interval, partly upon the amount retained of what was previously perceived. If the amount of time perceived during a particular time interval increases under one experimental condition and retention remains unaltered, the time interval should seem longer, i.e. we would obtain a larger past-time estimate. Conversely, a decrease in amount perceived should result in a smaller past-time estimate. If, on the other hand, perception of present time remains the same under two conditions and estimates of past time differ, the difference may be attributed to changes in retention of the **(previously perceived) time.**

The next question concerns the factors which affect the retention of time. Since we expect retention of time to be related to the retention of the processes which occupy the mental content, we may also expect a correspondence between the factors which influence the retention of these other processes and the factors **affecting retention of time.**

The mechanism underlying an improvement and an impairment of retention may be thought of in terms of an increased versus a decreased resistance to change of the brain traces made by previous impressions. Thus we expect retention of time to vary with resistance of the brain traces made by those impressions on which time experience is based.

A better retention usually implies that a larger number of previously acquired facts are correctly retained. In respect of retention of time we are solely concerned with the retention of the amount perceived. Since we assume that a partial forgetting or fading of previous impressions usually takes place so that less is retained than perceived (Hypothesis I), a better retention should serve to decrease the discrepancy between time per-

ceived and retained. Conversely, factors impairing retention of preceding events should increase this discrepancy.

A large number of factors are known to affect retention in learning experiments. For instance, such environmental or *external factors* as serve to focus the attention on the task generally improve retention. Likewise the similarity and dissimilarity between successive items or activities influence the memory processes. *Internal factors* or changes in mental alertness are also known to affect retention: on the whole, retention is better when the subject is alert than when he is drowsy.

When examining the factors influencing retention of time experimentally, changes in external factors may be brought about by procedures similar to those used in learning experiments. Changes in internal factors may be brought about with the aid of drugs affecting mental alertness.

The third hypothesis may be formulated as follows:

Hypothesis III. The retention of time perceived varies with factors affecting the retention of preceding mental processes on which the time experience is based. Under conditions which favour retention, more will be retained of the time units perceived within a given interval than under conditions which impair retention.

CHAPTER III

PREVIOUS INVESTIGATIONS

A brief review of some of the earlier investigations on time estimation will be given. The intention is not to give a complete historical survey, but to illustrate the sort of problems attacked, and the results obtained, by reference to some studies which may be considered representative of the work in this field. Earlier experiments which are directly related to the experiments in this investigation will be discussed in connection with these in the experimental section.

The literature on subjective time has been reviewed by several authors, among whom we may mention Nichols (1890), Weber (1933), Gilliland, Hofeld & Eckstrand (1946) and Woodrow (1951). Monographs on the subject have been written by Benussi (1913), Sturt (1925) and Fraisse (1957). William James treats these problems in a special chapter in his *Principles of Psychology* (1890, pp. 605–642). A chapter on subjective time is also found in Cohen's *Humanistic Psychology* (1958, pp. 96–116). Methods and terminology in studies on time estimation have been critically reviewed by Clausen (1950) and Bindra & Waksberg (1956). In a recent monograph Bünning (1958) treats the problem of endogeneous rhythms in animals and plants.

Methods and terminology

Estimates of 1-second intervals are usually examined by one of the following methods:

(a) The subject is instructed to count, usually to 30 or 60, at an estimated speed of one count per second. The results are expressed in terms of the relation between objective and sub-

jective time. If, for example, a subject counts to 30 in 15 objective seconds, 1 objective second corresponds to 2 subjective seconds, or 1 subjective second corresponds to 0.5 objective seconds.

The method of counting may be varied by asking the subject to tap a key, press a button, etc., at an estimated speed of 1 per second.

(b) 1-second estimates have been examined by the method of limits (Lhamon & Goldstone, 1956), where the subject is instructed to judge when a standard stimulus, the length of which is varied by the experimenter, equals one subjective second. The objective time corresponding to the subjective second is termed the second estimation point (SEP).

Estimates of 1-second intervals have been shown to vary considerably with the method of measurement (Goldstone, Boardman & Lhamon, 1958 *a*). Counting methods (counting aloud or counting to oneself) give objectively longer and more accurate estimates than estimates by the method of limits. This has been accounted for by the role played by kinesthetic cues in the "active" counting, as compared with "passive" estimates obtained by the latter method.

Estimates of intervals of more than 1 second are commonly studied by one of the following methods:

(a) The method of verbal estimation, where the subject is asked to estimate verbally the length of a preceding interval delimited by the experimenter.

(b) The method of production, where the subject is asked to delimit an interval verbally stated by the examiner. This method has also been referred to as the method of operative estimation (Clausen, 1950).

(c) The method of reproduction, where the subject is instructed to reproduce an interval delimited by the examiner.

Results obtained by these methods are usually expressed in terms of *overestimation* or *underestimation*. This terminology has led to considerable confusion, since over- and underestimation may refer either to the objective or to the subjective time. If, for example, an objective interval of 5 seconds is estimated as

8 seconds, this may be termed an overestimation if objective time is used as reference point and, conversely, an underestimation if the subjective estimate is used as reference point.

The influence of the type of activity

The nature of the task by which the subject is occupied has a considerable influence on the subjective duration. Axel (1924) showed that retrospective estimates of intervals between 15 and 30 seconds varied with the "level of behaviour" characterizing the interpolated activity. The higher the level of behaviour, the shorter was the estimated time. Thus intervals filled with a simple motor activity (tapping) were judged longer than the same intervals filled with cognitive tasks (analogies and number-series completion). Sensorimotor activities (cancellation) produced estimates of intermediate length. There was no significant difference between estimates of intervals filled with tapping (representing the "lowest level of behaviour") and empty intervals.

Gulliksen (1927) obtained results in essential agreement with Axel's in an experiment with a different set of tasks and time periods of 200 seconds.

Spencer (1921) and Swift & McGeoch (1925) stressed the effects of a passive versus active occupation. Equal objective periods were judged longer when, for instance, the subject was listening to a story read by the examiner than when he was reading himself.

Harton (1938*a*, *b*) investigated the effects of the difficulty of the task on time estimation and found that periods of time spent at difficult activities were estimated as shorter than equal periods spent at easy activities.

The influence of motivation

The effect of motivation on time estimation has been studied in experiments where the subject performs the same task under

objectively equal time periods, but under different conditions of motivation.

In an experiment by Rosenzweig & Koht (1933) motivation was varied by having subjects work at unsolvable puzzles (a) as part of an intelligence test and (b) for the purpose of practice. It was argued that "need-tension" would be greater in the former case. The results showed that time was estimated as shorter when need-tension was greater. The authors suggest that a desire for time to pass quickly may influence the subjective duration, time seeming relatively shorter when one wishes it to be long and relatively longer when one wants it to pass quickly.

Filer & Meals (1949) found that subjects motivated by an attractive goal to complete a task quickly estimated it as longer than subjects with no definite goal. These results are contradictory to those by Rosenzweig & Koht according to whom time seemed shorter when motivation was stronger. However, the results of the two experiments are consistent if interpreted in terms of the subject's desire for time to pass either slowly or quickly: time is dragging when we wish it to fly and vice versa.

The influence of a clearly defined goal was investigated by Harton (1939 *a*). Time was estimated as shorter when the subject was striving towards one definite goal than when the task involved several goals or one less clearly defined goal. The results were interpreted in terms of "unity of organization", greater unity tending to make time seem shorter. The finding that time seemed shorter when spent at successful activities than at failure (Harton, 1939 *b*) was also interpreted in terms of unity of organization, successful activities being considered to involve greater unity.

Hindle (1951) found time to be estimated as progressively shorter when the subject approached a clearly defined goal and she interpreted her results in terms of "perceived rate of progress".

The influence of physiological factors

Several attempts have been made to relate subjective time to physiological processes, most of which have yielded negative or

unreliable results. However, some interesting findings have been obtained in studies on the relation between *body temperature* and time estimation.

François (1927) changed the body temperature experimentally (up to 0.8°C) by diathermy. Time judgments were obtained by having the subject tap a Morse key at requested rates. The results showed an increase in speed of tapping with increased body temperature.

Hoagland (1933) investigated effects of temperature on the estimation of seconds by counting in two subjects with influenza and one subject in whom the temperature was raised by diathermy. His results agreed with those of François: during increased temperature rate of counting was faster. This was consistent with the subject's feeling that time passed more slowly when the temperature was high. Hoagland drew attention to the similarity between the effects of temperature on time estimation and on the speed of chemical reactions (Arrhenius' equation).

Other attempts to correlate time estimation and physiological variables have not been successful. Schaeffer & Gilliland (1938) failed to show any relation between time estimation and five physiological variables studied: pulse rate, heart work, breathing rate, breathing work and blood-pressure changes. Gardner (1935) in a study of time estimation in hyperthyroid and hypothyroid patients found no relation between basal metabolism and subjective time.

The influence of drugs

It is well known that some drugs, e.g. hashish and mescaline, produce drastic effects on the experience of time. However, these effects appear to be of a complex nature and the data reported contain many seemingly contradictory reports such as "Time seemed to fly" or "Time seemed like an eternity".

In a review of the effects of hashish Fränkel & Joël (1927) state: "Minuten erscheinen hinterher als Stunden, ohne doch

langsam vergangen zu sein, schliesslich verschwindet jedes Mass der Zeitschätzung — nur der Eindruck ungeheurer Zeitspanne bleibt, es wird von Jahrzehnten und Jahrhunderten gesprochen."

Bromberg (1934) states that during hashish intoxication time appears to be markedly lengthened, whereas in looking back the period seems extraordinarily compressed. He tried to account for the lengthening of time in passing by the "increased speed of associations and perceptions, the large number of experiences that crowd on the observer" which "give this subjective feeling inasmuch as we measure time subjectively by the regular recurrence of events."

Fernberger (1923) found that during mescaline intoxication "a given period of time seemed very much more extended than normally". He believes that the "rapidly changing focus of attention accounts for distortion of time. We normally judge a period of time by the 'filling', by the number of processes that have claimed the center of attention. Under the influence of peyote [mescaline] this filling, for a given period of time, is much increased and so the period seems extended."

Favilli (1937) states that in mescaline intoxication objectively short successive events appear extremely long while they are passing, whereas afterwards the total duration of such events seems short.

It is obvious from these studies that reports as to time seeming to pass more quickly or slowly than usual under the influence of drugs are not necessarily contradictory. On the contrary, there seems to be some agreement in that time seems longer than usual in passing, but shorter when regarded in retrospect.

Attempts to record quantitatively changes in time estimation induced by drugs with less drastic general effects than hashish and mescaline will be discussed in connection with our own drug experiments (Experiments 5, 12 and 13).

Time estimation in mental illness

Disturbances in time experience are commonly noted in mental illness, both in organic brain disease and in functional disorders. The clinically observed changes mostly refer to defects in temporal orientation, but changes in subjective impressions of the rate of passage of time are often mentioned. The main part of the literature in this field consists of case studies relating clinical observations rather than presenting experimental results. In many cases, e.g. Korsakow's psychosis, defective time estimation is regarded as secondary to memory disturbances (e.g. Brain, 1951, p. 953).

Lewis (1931) presents a sample of case studies of patients with functional disorders showing different types of disturbances in subjective time and Schilder (1936) in a review of the psychopathology of time describes a wide variety of changes in both organic and functional cases collected by himself and others.

These reports, as well as others, contain several apparently contradictory observations. In the same clinical condition time is sometimes reported as passing more quickly than usual, sometimes more slowly, or even as "standing still". Inspection of the data presented makes it evident that the contradictory statements are, at least partly, due to the fact that reference is sometimes made to objective and sometimes to subjective time. Furthermore, just as in the case of drug investigations, considerable confusion arises from the fact that emphasis is sometimes placed on impressions of time in passing and sometimes on retrospective estimates.

It is often claimed that the clinically observed changes cannot be recorded by objective techniques, i.e. estimates of short durations obtained by some of the common methods will not deviate from normal estimates, even when the patient clinically shows evidence of changes in time experience. However, some investigators using adequate controls and experimental procedures have been able to record significant quantitative differences in time estimation between normal and clinical groups. Lhamon & Goldstone (1956) found statistically significant differences be-

tween schizophrenic patients and normal controls in estimations of 1-second intervals. Using the method of limits they showed that 1 subjective second equalled 0.538 objective seconds in the control group and 0.308 objective seconds in the schizophrenic group. The authors conclude that: "This finding is apparently in line with the clinical observations of the inner-directed, autistic person's tendency to overestimate temporal events based upon external occurrences."

In an earlier study on depressed patients, Lhamon (1953) showed that counting at a subjective rate of 1 per second was slowest when the depression was most severe and that the speed gradually increased as the clinical condition improved after electroconvulsive treatment. These findings, as Lhamon points out, do not permit valid conclusions, since there were no control subjects. The data, however, are consistent with an observation by the same author, of a subject listening to standard time signals (radio ticks), appearing at a rate of 1 per second. The subjective rate of these ticks varied with the general activity level of the subject, sounding too far apart when the subject was active and too close when he was fatigued.

Subjective time scales

A few attempts have been made to study the relation between objective and subjective time by psychophysical scaling methods.

Gregg (1951) constructed a subjective scale for stimulus durations below 1 second; he found a linear relation between objective and subjective time within this range. Ross & Katchmar (1951) scaled time periods between 1 and 60 seconds. In this range the relation between objective and subjective time was non-linear. Stevens & Galanter (1957) found a slightly non-linear relation in the range 0.25 to 4 seconds. Ekman & Frankenhaeuser (1957) examined the relation between objective and subjective time for intervals between 1 and 20 seconds. Results obtained by the methods of ratio setting and ratio rating showed subjective time to be a positively accelerated function of ob-

jective time. It was pointed out that the curve obtained could be interpreted in terms of a retention curve. According to this interpretation, a positively accelerated function is obtained when the objective time is scaled with the (retained and thus decreasing) subjective amount of a preceding interval as the unit of measurement. A learning function, on the other hand, would be expected when elapsed time is scaled with a constant subjective unit of measurement.

PART II

CHAPTER IV

METHODS

The experiments to be reported may be grouped according to the problems to be investigated as follows:

(1) The relation between time perceived and time retained: Experiments 1–4.

(2) Conditions affecting perception of time: Experiments 5–9.

(3) Conditions affecting retention of time: Experiments 5 and 10–11.

This series of experiments was designed to test the hypotheses advanced in connection with each problem.[1]

(4) Finally two experiments were carried out for the purpose of examining effects of some drugs on the experience of time: Experiments 12 and 13.

Of our three main problems only the second may be approached by conventional methods of time estimation. Estimates of 1-second intervals as obtained by the method of counting or tapping at a subjective rate of 1 per second as well as by the method of limits as used by Lhamon & Goldstone (see p. 28) provide adequate measures of the perception of present time. However, with respect to the retention of previously perceived time, the situation is more complex. Measures of elapsed time as obtained by the method of verbal estimation will necessarily be affected both by the amount perceived and the amount retained. The same is true of measures obtained by the methods of production and

[1] Some of the experiments have been reported in a paper read at the XIIIth Congress of the International Association of Applied Psychology, Rome, April 1958.

reproduction, when the time intervals exceed the conscious present. A measure of retention of time cannot be obtained directly by any method, but it must be inferred from the relation between the estimated present and estimated past time. This implies that we need a method by which it is possible to keep under control the number of present-time estimates on which past-time estimates are based. Such a method was devised. It will be designated the method of present- and past-time estimation (PPT method).

A general outline of the methods used in the various experiments will be given below as well as a full description of the PPT method, which is our main experimental method. Details of the experimental procedure will be given separately for each experiment.

Methods used in various experiments

(a) Present- and past-time estimation: Experiments 1, 2, 5, 6, 8, 10, 12, 13.

(b) Counting at a subjective rate of 1 per second: Experiment 5.

(c) Tapping at a subjective rate of 1 per second: Experiments 5, 7.

(d) Determination of 1-second intervals by the "up-and-down" method: Experiment 9.

(e) Verbal estimation of elapsed time: Experiments 3, 4, 11.

(f) Production of time intervals: Experiment 5.

(g) Reproduction of time intervals: Experiment 5.

The method of present- and past-time estimation

In order to obtain combined measures of present and past time a situation should be arranged where the subject gives successive 1-second estimates without being able to count the number of such estimates given within a certain period of time. Thus the ordinary methods of counting or tapping at a subjective rate of 1 per second cannot be used. If, however, the subject is presented with a series of randomized digits and instructed to name them at a rate of 1 per second, this will rather effectively stop him from counting the number of such estimates given.

Digits between 1 and 9 were typed on a strip of paper in random order. The strip was mounted on a screen placed between experimenter and subject. As the subject pulled the paper, the digits appeared one at a time in a window in the screen in front of him. This arrangement prevented him from seeing the number of digits read, which might otherwise have provided him with a cue for his estimate of elapsed time. The subject was instructed to start reading the digits at a subjective rate of 1 per second at a ready signal, and to go on reading until interrupted by a stop signal. The number of digits read within an interval gave the subject's *present-time score.* (This was read off the back of the list which contained successive numbers visible only to the experimenter.)

The subject was instructed that immediately after the stop signal he should estimate verbally the length of the time period that had elapsed between the two signals. This estimate gave his *past-time score.* The instructions emphasized that the estimate should be based on "the immediate impression of how long the time felt" and not on attempted calculations of the number of digits read. The subject was also requested not to give rounded estimates, like "about 20 seconds", but to make his judgments as precise as possible. A minimum of three preliminary trials were always given in order to acquaint the subject with the procedure.

In most experiments five standard durations ranging from 12 to 53 seconds have been used. In some experiments the range of standards has been extended downward and in some upward, the shortest standard duration employed being 4 and the longest 72 seconds. (When standard durations below 12 seconds have been employed, the procedure has been somewhat modified, cf. Experiment 2.)

The standards have been presented to the subject in random order and the number of estimates obtained for each standard per subject has varied from one experiment to another, with a maximum of 10 and minimum of 4 for each experimental condition.

Scores.—By the method described we obtain three sets of scores for each subject and each standard duration:

(1) The present-time score, which is equal to the number of successive 1-second estimates given within one particular standard duration.

(2) The past-time score, which is the verbal estimate (in seconds) of the standard duration that has just elapsed.

(3) The retained-time score, which is obtained by calculating the quotient (past-time score)/(present-time score) for each particular standard duration.

For each set of scores we have a set of "sub-scores" for each subject, i.e. one for each standard duration. These sub-scores may be combined to one *total score* by calculating the sum of the mean estimates of each standard duration. We thus obtain for each subject one total score for present time and one for past time. A total score for retained time is obtained by calculating for each subject the sum of the mean quotients for the five standard durations.

Subjects.—The number of subjects used in the various experiments varied between 10 and 25. Altogether 67 subjects, 44 men and 23 women, participated in the investigation. The subjects were medical students and laboratory technicians aged 19 to 40 years (average 23 years).

CHAPTER V

THE RELATION BETWEEN PERCEPTION AND RETENTION OF TIME AND OF SENSORY STIMULI

The aim of the experiments to be described in this section was (a) to examine the relation between time perceived and retained (Experiments 1 and 2) and (b) to compare this relation with that between amount of sensory stimuli perceived and retained (Experiments 3 and 4).

We assume the retention of a time period to be related to the retention of the events filling this period. Since amount retained is generally less than amount perceived, we expect that past-time estimates will be smaller than the sum of the present-time estimates on which they are based (Hypothesis I). We also assume that the amount retained of a time period, on the one hand, and of the sensory stimuli filling this period, on the other, will follow the same general trend.

Experiment 1. Estimation of present and past time within the range 12 to 53 seconds

Most experiments in this investigation are restricted to time estimates within the range 12 to 53 seconds under various experimental conditions. Therefore we shall start the experimental section by examining data within this range obtained by the PPT method under control conditions. These data will serve to illustrate the relation between (a) objective time and estimated present time, (b) objective time and estimated past time, and (c) estimated present and estimated past time.

Hypothesis I states that past-time estimates are smaller than the sum of the present-time estimates on which they are based. The data to be presented here will be used for a first test of this hypothesis.

The data will also serve to illustrate inter- and intra-individual variability in scores for present, past and retained time as obtained by the PPT method, as well as possible systematic changes in time estimates at consecutive trials.

The data to be reported are the control data from an experiment with drugs (Experiment 5) obtained after the intake of a lactose placebo. Since the results are presented here mainly for the purpose of general illustration, a possible effect of the placebo will be of no consequence.

Procedure

Twenty-five subjects were examined by the PPT method. The standard durations used were 12, 21, 32, 42 and 53 seconds, presented to the subject in random order. Fifteen subjects gave 4 and 10 subjects 8 estimates of each standard duration.

Results

The means for the individual mean scores for present, past and retained time are shown in Table 1. The results are presented graphically in Fig. 1 where present- and past-time estimates are plotted against objective time.

The main characteristics of the experimental data are (a) that present-time estimates correspond fairly closely to objective time, (b) that estimates of past time are considerably smaller

TABLE 1. *Present, past and retained time within the range 12 to 53 seconds.*

Obj. time in sec. ...	12	21	32	42	53
Present time in subj. sec.	12.52	21.85	32.72	42.86	53.40
Past time in subj. sec.	9.67	16.45	23.26	30.43	39.17
(Past time)/(Present time)	0.7917	0.7714	0.7305	0.7245	0.7498

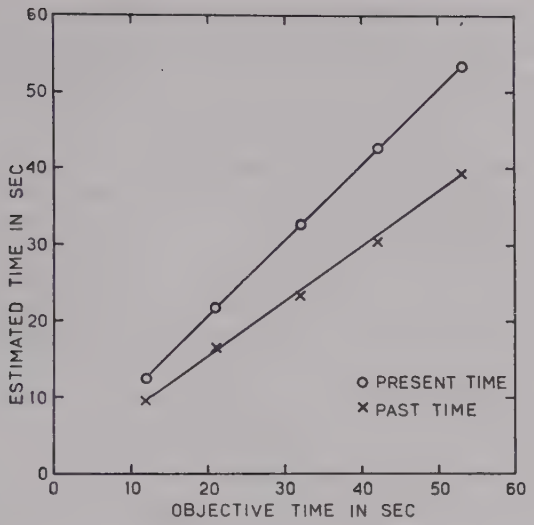

FIG. 1. Present- and past-time estimates within the range 12 to 53 seconds.

than both the objective time and the present-time estimates on which they are based, and that, consequently, (c) the quotients (past time)/(present time) are less than 1, the retention loss varying between 21 and 25 per cent for the various standard durations.

In order to test the significance of the differences between present- and past-time estimates, the mean intra-pair differences between present and retained time were submitted to the *t*-test. Table 2 shows the *t*-values obtained together with the mean

TABLE 2. *t-values for intra-pair mean differences between present- and past-time estimates within the range 12 to 53 seconds.*

Obj. time in sec. ...	12	21	32	42	53
Mean diff.	2.850	5.405	9.460	12.425	14.230
S.D. of diff.	3.083	5.347	7.776	9.378	12.188
t	4.531	4.954	5.961	6.492	5.719

$P = 0.001$ for $t = 3.467$; $df = 24$.

differences and their standard deviations. Since a difference in the obtained direction was predicted, the test is one-tailed. All t-values were highly significant ($P < 0.001$). Thus the results obtained are consistent with Hypothesis I.

Inter-individual differences were examined by computing the standard deviations for the 25 individual means at each standard duration and the corresponding coefficients of variation. It was seen that standard deviations for present- and past-time estimates increased with increasing length of the time period. Coefficients of variation ranged between 20.25 and 21.26 per cent for present-time scores, between 23.56 and 26.91 per cent for past-time scores, and between 25.38 and 27.35 per cent for retained time.

In order to obtain measurements of uncertainty of estimation which would be independent of inter-individual variation, *intra-individual variability* was examined by computing the square root of the average individual variance and the corresponding coefficients of variation. It was found that uncertainty of estimation increased with increasing length of the time period. Coefficients of variation for present-time estimates ranged from 5.39 to 7.37 per cent and for past-time estimates from 15.62 to 20.29 per cent. (Since scores for retained time are based on the *mean* estimates of each subject for present and past time, respec-

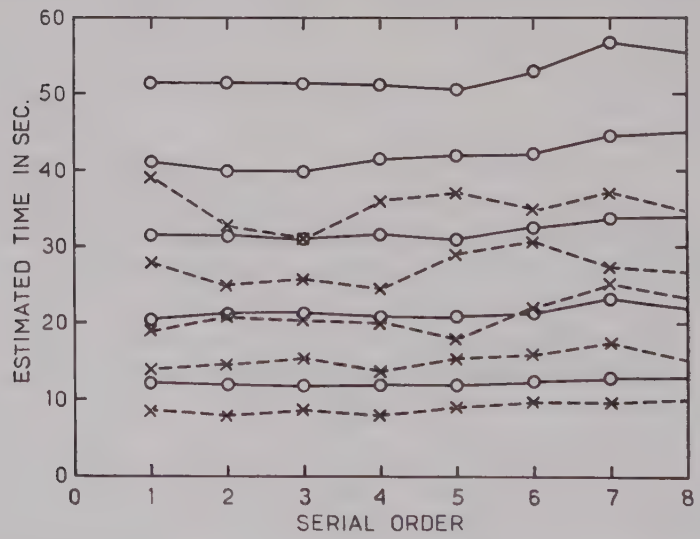

FIG. 2. Estimates of present time (○) and past time (×) for the five standard durations at successive trials.

tively, measurements of intra-individual variability are not available.) The results are presented in full in the Appendix, Tables I and II.

In order to examine possible *systematic changes* in estimates at consecutive trials within one experimental session, the means of the individual estimates at each presentation of the standard were computed. Fig. 2 shows the means of the present- and past-time estimates, respectively, obtained from the 10 subjects who gave 8 estimates of each standard duration. No consistent trend is seen.

Comment

The prediction that past-time estimates would be smaller than the sum of the present-time estimates on which they were based was verified by the results obtained. However, this prediction was based on the assumption that there occurred a retention loss, i.e. a contraction of previously perceived time caused by a fading of the processes to which the time experience was associated. Consequently we would expect the discrepancy between present- and past-time estimates to increase with increasing length of the time period yielding progressively lower retention quotients. Only a slight tendency towards a decrease in the quotients was seen, indicating that the relation between time perceived and retained remained fairly constant within the range 12 to 53 seconds.

In order to confirm the assumption that the difference between present- and past-time estimates is associated with a retention loss, the range over which measurements are obtained must be extended. An experiment where a wider range of time periods is employed will be described next.

Experiment 2: Retention of time intervals between 4 and 53 subjective seconds

The aim of this experiment was to examine the relation between present- and past-time estimates within the range 4 to 53 seconds. We expect that short intervals will be more or less unaffected by memory factors in which case the past-time estimate will lie relatively near the sum of the corresponding present-

time estimates. For longer intervals, the discrepancy between present- and past-time estimates should increase as retention loss increases.

The data presented from the experiment with intervals between 12 and 53 seconds showed only a slight tendency for the quotient (past time)/(present time) to decrease within this region. This indicates that the major part of the forgetting which is assumed to take place within 53 seconds occurs within the first 12 seconds.

In order to verify the assumption that the quotient decreases with increasing length of the time interval, though it soon reaches a relatively stable level, the range of the intervals examined was extended downward.

It should be pointed out that the PPT method does not permit measurements or durations below 1 subjective second and that, by definition, the present- and past-time estimates obtained coincide at 1 subjective second. In other words, the quotient is 1 at this point. The lower range of the intervals selected for study was placed at some distance from this point, i.e. at 4 *subjective* seconds. A modification of the procedure, as described below, was necessary to make possible measurements of these short intervals.

Procedure

Twenty subjects participated in the experiment. The PPT method was modified in the following way:

Instead of using standard durations of a fixed objective length the number of subjective seconds was kept constant. The subject's task remained exactly the same, but the stop signal given by the experimenter at the end of the period to be estimated in retrospect was not given after a certain physical time period had elapsed, but when the subject had completed a certain number of 1-second estimates. The standard intervals thus determined were 4, 5, 6, 7, 8, 10, 12, 15, 21, 32, 42, and 53 subjective seconds. These were presented in random order and each subject gave six estimates of each interval. The past-time estimate was obtained in the usual way and the objective time corresponding to

the number of subjective seconds was recorded to the 0.001 second by an electronic decade counter. The score for retained time was obtained by calculating the quotient between the past-time estimate and the present-time estimate, the latter being in this case equal to the standard.

Results

The means of the individual mean scores for past and retained time as well as for the objective time corresponding to the standard durations are shown in Table 3.

TABLE 3. *Present, past and retained time within the range 4 to 53 subjective seconds.*

Standard: Present time in subj. sec.	Obj. time in sec.	Past time in subj. sec.	(Past time)/ (Present time)
4	4.43	3.80	0.9492
5	5.67	4.65	0.9297
6	6.74	5.56	0.9270
7	7.82	6.37	0.9100
8	8.97	7.15	0.8940
10	11.07	8.60	0.8600
12	13.27	8.88	0.8223
15	16.64	11.96	0.7973
21	23.37	15.75	0.7498
32	35.80	24.46	0.7645
42	46.56	31.61	0.7525
53	59.03	40.07	0.7556

It is seen that the past-time estimates are consistently lower than the corresponding present-time estimates (standard durations) and objective durations. Accordingly the quotients (past time)/(present time) are less than 1. Furthermore the quotients decrease with increasing length of the time period up to the 21-second duration from which point onwards they remain fairly constant. Thus the results are consistent with our assumptions. The relation between the quotient and the objective time period is illustrated graphically in Fig. 3.

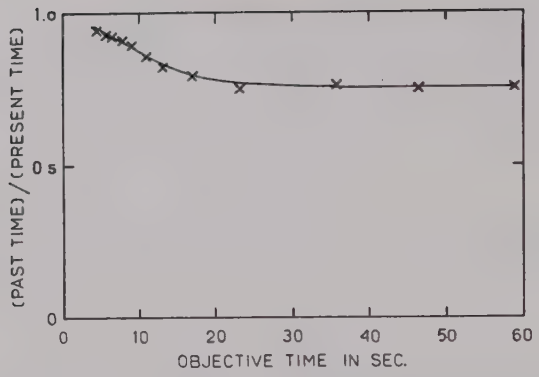

FIG. 3. Quotients for retained time within the range 4 to 53 subjective seconds.

Comment

One striking point in the results is that the quotient at 4 seconds is considerably less than 1. This indicates that the 4-second interval lies beyond the conscious present for some subjects. (Ten subjects had quotients less than 1, six subjects had quotients of 1.0 and the remaining four had quotients slightly greater than 1 at the 4-second interval.)

This experiment also confirms the data from the previous experiment with intervals between 12 and 53 seconds, in showing that the level of retention remains fairly constant within this range. The curve of retained time does not show the steep initial fall characteristic of curves of retention in learning experiments, but the decrease in this case is more gradual. However, a close resemblance to a curve of retention as obtained in learning experiments is not to be expected, since such a curve is obtained by testing the retention at various intervals after the presentation of the material. In our experiment retention is always tested immediately after the presentation of the material and what is varied is the time of presentation (i.e. the amount presented). Thus the retention of elapsed time intervals of various lengths resembles, in certain respects, retention as measured in a learning experiment where lists of different

lengths are employed; the amount retained decreases with increasing length of the time interval and learning list, respectively.

A consideration of the retention of intervals beyond 53 seconds involves speculation. It seems reasonable to assume that the retention loss continues, though possibly at a very slow rate. It is also possible that a retrospective estimation of longer intervals is governed by some totally different mechanisms. When measurements are obtained in a laboratory situation, it is difficult to avoid introducing new factors when the experiment is extended to include longer time periods. In particular, the factor of boredom must be expected to play a dominant role in experiments which utilize a monotonous filling of the time periods, as is the case in this investigation. Already at intervals of 42 and 53 seconds many subjects found the reading of digits rather tedious. (At intervals of 72 seconds, as used in some experiments to be described, this symptom became even more marked.) It is thus possible that estimates of longer intervals are affected by factors not present in the estimation of shorter intervals. Consequently data regarding the retention of longer intervals should preferably be obtained by some other method.

Most experiments by previous investigators have not been designed to answer the question of the relation between retention of short and long intervals. Systematic investigations are almost exclusively concentrated on intervals shorter than 53 seconds. However, an experiment by Cohen, Hansel & Sylvester (1954) has some relevance in this connection. They investigated the relation between estimated and objective time for periods extending over several years by instructing their subjects to mark off on a horizontal line, the entire length of which represented life from birth to "now", the seeming length of the interval since a given past event. When estimated time was plotted against the logarithm of objective time, a reasonable fit to a straight line was obtained for intervals up to 6 months from "now". (For longer periods the relation was linear, which the authors believed to be due to an inability of the subjects to judge these long periods except by calculation on a chronological basis.) The authors interpret their results in terms of Fechner's law,

but mention as an alternative hypothesis that "the seeming length of an interval may be a function of the retention of the activity during the interval and, as retention diminishes with time, there might be a corresponding contraction of time intervals". This hypothesis is in essential agreement with our Hypothesis I, which is based on the assumption of an analogy between the fading of memory traces of mental events and the apparent contraction of time.

Experiment 3: The relation between number of seconds retained and number of digits retained. A

The aim of this experiment was to examine the relation between the number of subjective seconds and the number of digits retained. As pointed out earlier, the retention of time is not expected to be related to the correct retention of specific items, but to the *amount* of experience retained. Thus an ordinary learning experiment does not serve as a parallel to an experiment on retention of time. Instead the retention of amount of stimuli perceived during intervals of different length will be examined. Since the amount, i.e. the number of items, perceived increases with the length of the interval, the situation will parallel a learning experiment where the amount retained of successively longer tasks is studied. It is expected that retrospective estimates of amount of stimuli perceived will show the same general characteristics as the retrospective estimates of time intervals, i.e. less will be retained than was perceived and retention loss will increase as the amount perceived increases.

It is obviously impossible to obtain estimates of number of digits read which are independent of number of seconds, when the subject is instructed to read digits at a rate of 1 per second. The procedure was therefore modified as described below.

Procedure

Ten subjects participated in the experiment. The strip with digits was employed as in the previous experiments, but the subjects were instructed to read digits as *rapidly* as possible.

Immediately following the stop signal they were asked to estimate (a) the length of the interval in half of the trials and (b) the number of digits read within the interval in the other half of the trials. The two tasks were rotated. The intervals used were 4, 7, 12, 21, 32, 42 and 53 seconds. Each subject gave 4 estimates of time and 4 of amount for each interval.

Since no present-time estimates were obtained, the true retention quotient could not be calculated in this experiment. A retention score was obtained by calculating the quotient (past time)/(objective time). The discrepancy between the true quotient and the one calculated equals the discrepancy between the estimated and the objective second. This discrepancy will hardly matter in this case, where we are only concerned with a comparison between the general trend of retention of time and of amount. A measure of the amount of digits retained was obtained by calculating the quotient (estimated number of digits)/(objective number of digits).

Results

Means of the individual mean scores for past and retained time and for objective, estimated and retained amount are shown in Table 4.

TABLE 4. *Estimates of past time and of amount (number of digits) read.*

Obj. time in sec. ...	4	7	12	21	32	42	53
Past time in subj. sec.	4.45	6.88	12.10	18.83	26.13	33.75	37.65
(Past time)/ (Obj. time)	1.1125	0.9821	1.0083	0.8964	0.8164	0.8035	0.7104
Obj. amount	9.50	16.23	27.15	46.28	69.25	90.10	111.68
Estimated amount	7.00	10.33	15.28	24.60	33.50	40.25	48.00
(Est. amount)/ (Obj. amount)	0.7352	0.6401	0.5709	0.5324	0.4921	0.4517	0.4389

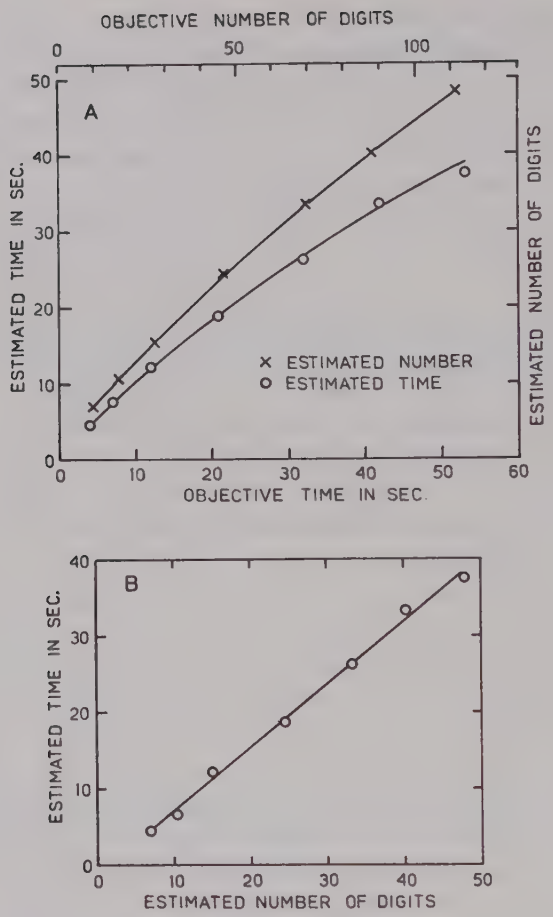

FIG. 4. The relation between estimated time and estimated amount. *Diagram A:* Estimated past time plotted against objective time and estimated number of digits plotted against objective number of digits. *Diagram B:* Estimated past time plotted against estimated number of digits.

The relation between estimated past time and objective time is the same as in previous experiments, estimated time being consistently shorter than objective. Similarly, the estimated number of digits is consistently smaller than the actual number.

Both sets of data show the same general trend; the discrepancy between objective and estimated magnitude increases with increasing magnitude, i.e. increasing length of the time interval. The results are illustrated graphically in Fig. 4 A and B.

Comment

As pointed out above, the quotients for retained time obtained in this experiment are not strictly comparable with the true retention quotients obtained in other experiments. The difference between the true retention quotients and those obtained depends upon the discrepancy between the objective and the estimated second, of which we have no information.

The fact that quotients for retained amount of digits are much lower than the corresponding quotients for retained time is a natural consequence of the difference in objective magnitude between number of seconds and number of digits read, the latter being more than twice as many as the former within each standard interval. The present experiment thus only serves to show that the retention of amount of stimuli perceived and of time perceived follow the same general trend. In order to obtain measures of the two retention processes which are more strictly comparable, the two objective magnitudes, number of seconds and number of stimuli, should be identical. Such an experiment will be described next.

Experiment 4: The relation between number of seconds retained and number of digits retained. B

The aim of this experiment was to investigate the relation between the retention of digits read and number of seconds passed, in a situation where the objective amount of digits and seconds was identical.

Procedure

Fifteen subjects participated in the experiment. They were instructed to read digits in pace with a metronome beating at

various frequencies. After the presentation of each standard duration the subject was asked to give two estimates, one of the time that had elapsed and one of the number of digits read within the interval. The instructions emphasized that the rate of the metronome beats would vary throughout the experiment, that the number of digits read and seconds passed would hence usually not be identical and that the two estimates had to be given independently of each other. It was stressed that both estimates should be based on the subjective feeling of the length of the time elapsed and the number of digits read, respectively, and not on attempted calculations.

Only estimates obtained when the metronome was beating at a rate of 1 per second were recorded. The trials with the metronome beating at other frequencies served to confuse the subject and prevent him from forming a fixed opinion of the relation between time and number of digits. The 1 per second trials were randomly spaced between trials with the metronome beating at other frequencies ranging between 40 and 120 beats per minute.

The standard intervals were 4, 12, 21 and 32 seconds. Ten estimates of each standard were obtained from 5 subjects and 5 estimates from 10 subjects.

Results

Means of the individual mean scores for past and retained time and for past and retained amount are shown in Table 5. It is seen that there is a close correspondence between the retention of past time and retention of amount of digits read. In both cases the estimated magnitude is less than the objective. This discrepancy increases with increasing length of the time period, the main retention loss occurring within the first 12 seconds, a result in agreement with those obtained in the previous experiments.

These results are consistent with the assumption that experience of time is closely related to the experience of other events in showing that the retention of a time period closely follows the retention of the amount of stimuli filling this period.

TABLE 5. *Estimates of past time and of amount (number of digits) read in pace with a metronome beating at 1/sec.*

Obj. time in sec. ...	4	12	32	53
Past time in subj. sec.	4.03	8.43	19.63	31.68
(Past time)/(Obj. time)	1.0079	0.7019	0.6133	0.5977
Obj. amount ...	4	12	32	53
Estimated amount	3.88	8.55	19.53	33.07
(Est. amount)/(Obj. amount)	0.9688	0.7125	0.6104	0.6239

It is necessary to make sure that the estimate of time and of number of digits have been made as two separate estimates, so that the close agreement between the means of the two sets of estimates does not arise from the fact that the subject actually estimated one and the same thing. Inspection of the individual records shows that this is not the case. Six subjects more or less consistently gave lower estimates of amount than of time, in five subjects the relation was the reverse, and 4 subjects showed no definite tendency in either direction. In 69 out of the 320 pairs of estimates the two estimates were identical.

Comment

Since present-time estimates were not obtained in this experiment, it has not been possible to get true measures of the retention of time. The only measure provided of time retained is that obtained by calculating the quotient (past time)/(objective time). The fact that the quotients are, on the whole, lower in this experiment than in the previous experiments may simply be a consequence of the discrepancy between the objective and the estimated second. We do not know either the magnitude or the direction of this discrepancy. It is also possible that the relatively low quotients are associated with an actual increase in retention loss in this experiment as compared with the other

experiments. A more naive attitude towards time experience in this situation, where attention had to be focussed on the metronome beat, may also have influenced the estimates.

Summary of experiments 1 to 4

The relation between time perceived and retained was examined in Experiments 1 and 2. It was shown that the estimates of past time were consistently smaller than the present-time estimates on which they were based, i.e. the amount retained was less than the amount perceived. The discrepancy between time perceived and retained increased with increasing length of the time interval reaching a relatively stable level at intervals of about 20 seconds.

In Experiments 3 and 4 the amount of time retained was compared with the amount retained of the stimuli perceived within this time period. A close correspondence was found between amount of time retained and amount of stimuli retained.

The results of these experiments are in full agreement with Hypothesis I.

CHAPTER VI

PERCEPTION AND RETENTION OF TIME AS AFFECTED BY VARIATIONS IN INTERNAL CONDITIONS

Changes in mental alertness may be expected to be accompanied by changes in both amount of mental content and memory processes. If mental alertness is increased by stimulants, we may expect the amount of mental content per objective time unit to increase and retention to improve. Conversely, if mental alertness is decreased by sedatives, we may expect amount of mental content to decrease and retention to deteriorate. Since we assume that perception of present time varies with the amount of mental content and retention of past time with memory processes, both present and retained time should vary with degree of mental alertness.

Experiment 5: Effects of pentobarbital and methamphetamine

The aim of these experiments was to study time estimation as affected by various degrees of mental alertness. A sedative, pentobarbital, was used to decrease, and a stimulant, metamphetamine, to increase mental alertness. A lactose placebo was used as a control.

The experimental series may be divided into three parts:

(1) *The main experiment, carried out by the method of present- and past-time estimation* (*PPT method*).—The following predic-

tions were made: (a) On the basis of Hypothesis I, past-time estimates were expected to be smaller than the corresponding present-time estimates under all experimental conditions. (b) On the basis of Hypothesis II the two drugs were expected to exert a reverse influence on the *perception* of time. It was predicted that the objective second would seem subjectively shorter (smaller present-time estimates) under the influence of pentobarbital than under the influence of methamphetamine. (c) On the basis of Hypothesis III *retention* of past time was expected to differ under the two drug conditions. It was predicted that less would be retained of the time perceived (smaller retained-time scores) under the influence of pentobarbital than under metamphetamine.

(2) Estimation of time by the methods of *counting* and *tapping* at an estimated speed of 1 per second, and *production* and *reproduction* of 10-second intervals.

The 1-second estimates obtained by tapping and counting were expected to show the same characteristics as the present-time estimates obtained by the PPT method. Thus the objective time taken to complete the counts or taps would be longer under pentobarbital than under metamphetamine.

Productions were also expected to differ under the experimental conditions. Subjectively shorter objective seconds should result in longer productions and, similarly, a faster rate of forgetting may be assumed to result in longer productions. Thus it was predicted that productions would be objectively longer under pentobarbital than under metamphetamine. (It should be noted that the part played by changes in perception and retention of time cannot be differentiated in estimates obtained by this method.)

Reproduction of time intervals provide complex measures of time estimation. What the subject is reproducing is the memory of his perception of the stimulus duration. Thus memory processes enter both into the estimate of the preceding standard and into the estimate of the duration being produced. Likewise perception of time is likely to differ under the passive listening and the active reproduction. On the basis of these considerations

it was not thought possible to predict in what way reproductions should be affected by the drugs.

(3) *Performance tasks.*—Personal tempo, word fluency and mirror drawing were examined in order to secure some information as to the more general effects of the drugs. Personal tempo was expected to be slower and word fluency to be decreased under pentobarbital as compared with metamphetamine. Similarly, mirror drawing was expected to be better under metamphetamine than under pentobarbital both in respect of time and error scores. (Effects of stimulants and barbiturates on motor performance have been described by previous investigators, e.g. Wilson *et al.*, 1950, and Dicker & Steinberg, 1957.)

Procedure

General design.—Twenty-five subjects participated in the experiments. Each subject came to three sessions and the experimental conditions were rotated according to the following pattern:

Subject	*First session*	*Second session*	*Third session*
1	Control	Pentobarb.	Metamph.
2	Pentobarb.	Metamph.	Control
3	Metamph.	Control	Pentobarb.
4	Control	Metamph.	Pentobarb.
5	Metamph.	Pentobarb.	Control
6	Pentobarb.	Control	Metamph.
etc.			

This design was repeated for 27 subjects (15 according to 1, 2, 3 above and 12 according to 4, 5, 6 above). Two subjects were excluded before finishing the series, thus leaving a total of 25 subjects. The intervals between sessions ranged between a minimum of two and a maximum of five days.

One subject was excluded since she reported having changed her "internal" standard of 1 second completely in the middle of the second session. The other subject was excluded because his time estimates obtained by the PPT method fell totally outside the normal range, e.g. at the 12-second interval his present-time score was regularly 4 and his past-time estimates 3 seconds.

DRUGS.—Capsules with either 200 mg pentobarbital, 10 mg metamphetamine or lactose placebo were taken by mouth 1 hour and 15 minutes before the beginning of the experiments, which were carried out in the morning after a fast of 12–16 hours. (One subject, whose body-weight was considerably below average, 39 kg, received only half of these doses.) The doses of pentobarbital and metamphetamine were chosen so as to produce distinct feelings of drowsiness or alertness without extreme effects which might affect the subjects' ability to cooperate in the experiments. All capsules were identical in appearance and the subjects were not told which they received.

EXPERIMENTS.—(1) The main experiment was carried out by the method of *present- and past-time estimation*. Four estimates of each standard duration under each experimental condition were obtained for the first 15 subjects, and 8 estimates for the last 10 subjects. The standard durations were 12, 21, 32, 42 and 53 seconds.

(2) The other methods for studying time estimation were:

Counting to 30 at a subjective rate of 1 per second. The score was the average time taken to complete 5 consecutive counts.

Tapping at a subjective rate of one per second. The score was the average time taken for 30 taps on 5 consecutive trials.

Production of 10-second intervals. The subject was instructed to produce subjective 10-second intervals by pressing a key connecting a tone generator giving a signal in the earphones worn by the subject. Responses were recorded by an ink-writer. The subjects were instructed to refrain from counting. The score was the average time of 5 consecutive productions.

Reproduction of 10-second intervals. The procedure was the same as in the production experiments except that the subject reproduced a 10-second signal given by the experimenter. The score was the average time of five consecutive reproductions.

(3) The following performance tasks were used:

Personal tempo. The task was to tap a key at a comfortable rate. The taps were recorded by an electric counter. The score

was the mean number of taps in 5 consecutive 30-second periods.

Word fluency. The task was to write down as many words as possible which start with *s* and end with *a*. The time was $2\frac{1}{2}$ minutes and the score was the number of correct words.

Mirror drawing[1]. The task was to move a stylus along a slit (visible only in a mirror) cut out in a metal plate so as to form a 5-pointed star. The slit had saw-tooth notches along both margins. The notches served to make the task more difficult by catching the stylus. The time taken to complete one run was measured with a stop-watch, and the time of contact between the stylus and margins was recorded on an electric counter. The time score was the mean time taken to complete 8 consecutive runs and the error score the mean time in contact with margins. All subjects had received preliminary training on this test. (In half of the trials each contact of the stylus with the margin was accompanied by a sound from a buzzer which served as a stressor. Since there was no marked difference between trials with and without buzzer, the two sets of scores were combined.)

One experimental session lasted about 1 hour. Each task was preceded by warming-up trials. The number of subjects participating in the various tasks and the order of administration were: 1. Production (15 subjects), 2. Reproduction (15 subjects), 3. Personal tempo (25 subjects), 4. Tapping (25 subjects), 5. Word fluency (15 subjects), 6. PPT method (25 subjects), 7. Mirror drawing (9 subjects), 8. Counting (25 subjects). At half of the sessions counting preceded tapping.

Results

(1) The means of the 25 individual mean scores for *present*, *past* and *retained time* obtained by the *PPT method* are shown in Table 6. The table gives the following information: (a) Past-time estimates were consistently smaller than present-time estimates under all experimental conditions. (b) Present-time

[1] The apparatus was devised by Dr I. Dureman and Mr E. Österberg, the Psychological Laboratory, Psychiatric Clinic, Uppsala, who kindly put the design at our disposal.

TABLE 6. *Present, past and retained time after intake of pentobarbital, placebo (control condition) and metamphetamine.*

Obj. time in sec. ...	12	21	32	42	53
Present time in subj. sec.					
Pentobarb.	12.24	21.11	31.54	40.96	51.20
Control	12.52	21.85	32.72	42.86	53.40
Metamph.	13.04	22.87	34.07	44.70	55.87
Past time in subj. sec.					
Pentobarb.	8.64	13.86	21.22	28.39	35.10
Control	9.67	16.45	23.26	30.43	39.17
Metamph.	10.03	17.43	24.60	32.22	38.77
(Past time)/(Present time)					
Pentobarb.	0.7232	0.6792	0.6908	0.7101	0.7088
Control	0.7917	0.7714	0.7305	0.7245	0.7498
Metamph.	0.7986	0.7915	0.7501	0.7532	0.7231

estimates were consistently smaller under pentobarbital than under metamphetamine, and control scores fell between these two sets of drug scores. (c) Past-time estimates were consistently smaller under pentobarbital than under metamphetamine, four of the control scores lying between these two sets of drug scores. (d) Scores for retained time were consistently lower under pentobarbital than under metamphetamine, four of the control scores being again intermediate. The differences between the two drug conditions are represented graphically in Fig. 5 A and B.

In order to make possible overall tests of significance of the five differences between the three experimental conditions, the sum of the mean present- and past-time estimates, respectively, of each standard duration was calculated for each subject. Similarly the sum of the mean quotients (past time)/(present time) was calculated for each subject. The intra-pair mean differences between the *total scores* thus obtained were submitted to *t*-tests. Since the differences were in the predicted direction the tests are one-tailed. The *t*-values obtained are shown in Table 7.

The table shows that the differences in present, past and retained time under the two drug conditions were statistically

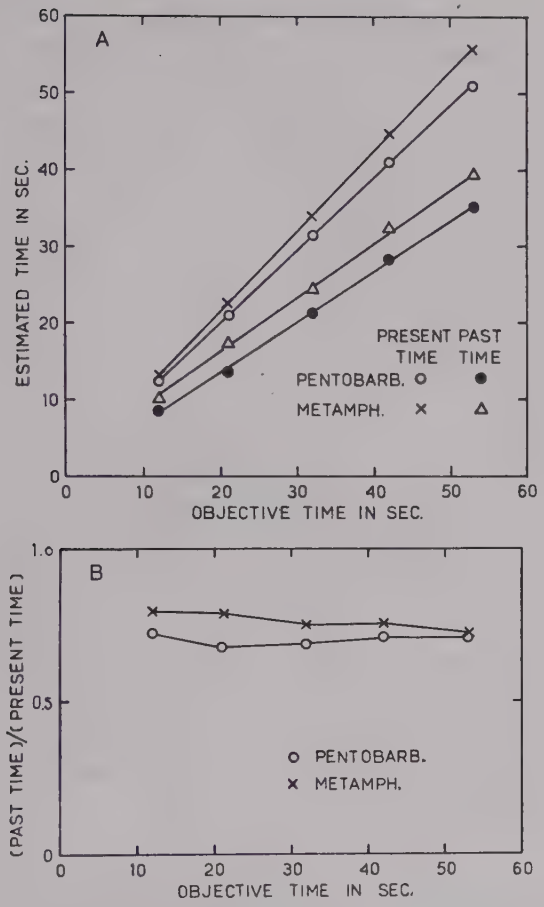

FIG. 5. Time estimates after intake of pentobarbital and metamphetamine. *Diagram A:* Present- and past-time estimates. *Diagram B:* Quotients for retained time.

significant. These results support Hypotheses II and III. The differences between control scores and the two sets of drug scores, though in the predicted direction, reached significance only in two cases.

Measures of variability are shown in the Appendix, Tables III and IV. (For variability of control scores see Appendix, Tables I and II.)

TABLE 7. *t-values for intra-pair mean differences between pentobarbital (P), metamphetamine (M) and control (C) scores.*

Variable	*t*-value		
	P – M	P – C	M – C
Present time	– 2.240	– 1.530	+ 1.640
Past time	– 4.310	– 3.686	+ 1.310
Retained time	– 3.025	– 2.327	+ 0.533

$df = 24$; $P = 0.05$ for $t = 1.711$; $P = 0.01$ for $t = 2.492$; $P = 0.001$ for $t = 3.467$.

TABLE 8. *Time taken to complete 30 counts and taps at an estimated speed of 1/sec. and time for production and reproduction of 10-sec. intervals under pentobarbital, control and metamphetamine conditions. Time in objective sec.*

Task	Pentobarb.	Control	Metamph.
Counting	33.13	30.82	29.74
Tapping	30.87	27.82	27.62
Production	9.40	8.58	7.79
Reproduction	8.47	8.41	8.58

(2) Results obtained in experiments on *counting* and *tapping* at an estimated speed of 1 per second and *production* and *reproduction* of 10-second intervals are shown in Table 8. It is seen (a) that counting and tapping were both slowest under pentobarbital and fastest under metamphetamine, and (b) that productions were longest under pentobarbital and shortest under metamphetamine, and (c) that reproductions did not differ noticeably under the three conditions.

Intra-pair mean differences in scores obtained in counting, tapping and production were submitted to *t*-tests. Since all differences were in the predicted direction the tests are one-

TABLE 9. *Personal tempo (number of taps), word fluency (number of words) and mirror drawing (time and error scores in sec.) under pentobarbital, control and metamphetamine conditions.*

Task	Pentobarb.	Control	Metamph.
Personal tempo	46.79	56.89	60.32
Word fluency	23.60	25.60	26.20
Mirror drawing, time	19.19	17.66	14.88
Mirror drawing, error	1.88	1.57	1.41

tailed. The differences between scores obtained under the two drug conditions were in all cases significant at the 0.05 level. (Counting: $t = 1.803$ and Tapping: $t = 1.833$, $df = 24$; Production: $t = 2.624$, $df = 14$.) The differences between the pentobarbital and control condition were also significant at the 0.05 level, whereas the metamphetamine scores did not differ significantly from the control scores.

(3) Results obtained in *personal tempo*, *word fluency* and *mirror drawing* are shown in Table 9. Inspection of the table shows (a) that personal tempo was slowest under pentobarbital and fastest under metamphetamine, (b) that word fluency was slightly decreased under pentobarbital and increased under metamphetamine and (c) that mirror drawing was impaired under pentobarbital and improved under metamphetamine, both in respect of speed and accuracy.

Intra-pair differences between means were submitted to one-tailed *t*-tests. With the exception of word fluency, the differences between the two drug conditions were significant (Personal tempo: $t = 4.002$, $P < 0.001$, $df = 24$; Mirror drawing, time: $t = 2.556$, $P < 0.05$, and error $t = 1.804$, $P \sim 0.05$, $df = 8$). Only in one case was the difference between pentobarbital and control scores significant (Personal tempo: $t = 3.871$, $P < 0.001$). Also in respect of metamphetamine and control scores, only one of the differences reached significance (Mirror drawing, time: $t = 2.655$, $P < 0.05$).

Comment

Changes in present-time estimates were demonstrated by the PPT method as well as in counting and tapping experiments. In all cases the changes obtained were in the predicted direction showing that the objective second was subjectively shorter under pentobarbital than under metamphetamine. Results in agreement with these have been obtained in a study by Goldstone, Boardman & Lhamon (1958 *b*) on the effects of seco-barbital and dextro-amphetamine on 1-second estimates obtained by the method of limits.

The data obtained by the PPT method also showed that less was retained of a passed time interval under pentobarbital than under metamphetamine, a result in agreement with the prediction.

The results obtained by the production method may also reflect changes in retention, since an increased rate of forgetting should result in objectively longer productions as obtained under pentobarbital. However, as pointed out before, a decrease in the subjective length of the objective second should also lead to longer productions and data obtained by this method cannot be analyzed into the two components, perception of present time and retention of past time. The same is true of the results obtained by Hormia (1956), who found longer productions of 10- and 20-second intervals after intravenous injections of isomyl.

The method of reproduction, as pointed out before, gives highly complex measures of time perception. It was included in the present experiment merely because it has been commonly used in studies of time perception in various clinical groups. The failure of most of these studies to demonstrate any differences may be due, not to an actual lack of differences between groups, but to a lack of differential sensitivity of the method. Our data support the latter alternative since, in contrast with results obtained by all the other methods used, the reproductions showed no differences under the three experimental conditions. These results agree with those obtained by Clausen (1950) in his comparison between methods of time estimation employed in an investigation of various clinical groups.

The reason for including the performance tasks was to check the effects on general efficiency of the doses of the drugs used. The results indicated the doses to have been fairly adequate. (For a general discussion on effects of stimulants and depressants on performance, see Eysenck, 1957, pp. 233–249.)

Inter-individual differences in reaction to these drugs are known to be large. Also these subjects reacted differently as judged from introspective accounts and the examiner's observations of their general behaviour. No attempts were made to record objectively effects other than those measured by the methods described, and the question of subjective versus objective effects was not investigated. On the whole, however, pentobarbital produced more pronounced symptoms, both objective and subjective, than metamphetamine. No marked effects of placebo on general behaviour were noticed: three subjects reported feeling somewhat more alert and one sleepier than usual.

Summary

Time estimation as affected by various degrees of mental alertness was studied. A sedative, pentobarbital, was used to decrease alertness and a stimulant, metamphetamine, to increase alertness. A lactose placebo was used as a control. The main experiment was carried out by the method of present- and past-time estimation.

It was assumed that a change in mental alertness would be accompanied (a) by changes in the amount of mental content per objective time unit and, hence, present-time estimates would be affected (Hypothesis II) and (b) by changes in memory processes, which would affect retention of past time (Hypothesis III).

On the basis of these assumptions it was predicted that scores for present and retained time would both be smaller after intake of pentobarbital than after intake of metamphetamine.

The results obtained agreed with the predictions and thus support Hypotheses II and III. Further support was obtained for Hypothesis I, since past-time estimates were consistently

smaller than present-time estimates, the differences decreasing when conditions favoured retention.

Data obtained by other methods of time estimation were consistent with the results obtained by the method of present- and past-time estimation.

Results obtained in performance tasks indicated decreased efficiency after intake of pentobarbital and increased efficiency after intake of metamphetamine.

CHAPTER VII

PERCEPTION OF TIME AS INFLUENCED BY VARIATIONS IN EXTERNAL CONDITIONS

In the previous experiment it was shown that the estimated duration of 1 second varied with the degree of mental alertness as influenced by drugs. These results were consistent with Hypothesis II according to which the objective second should seem subjectively longer when the amount of mental content is increased.

The aim of the experiments to be reported next was to examine the relation between the objective and estimated second as influenced by variations in the external stimulus conditions.

Results obtained by previous investigators showing that time estimates vary with external conditions, such as type of activity, do not provide any information as to whether the effects observed were related to changes in the perception of seconds or to changes in the retention of time.

We cannot obtain successive 1-second estimates by a subject in a situation where he is occupied by other activities, but we may change the external conditions under which estimates are obtained by varying the background. Since the stimuli in the background must not prevent the subject from performing the task of estimating seconds, we are restricted to the use of relatively few and not too drastic changes in the stimulus background.

It is reasonable to assume that the amount of mental content is related to the amount of external stimulation in a general way, so that the amount of mental content is increased or decreased when external stimulation is increased or decreased, respectively.

Consequently we may also expect to find a relation between the amount of external stimulation and the duration of the subjective second. Although variations of environmental factors are not likely to drastically influence the amount of mental content, the subject will at least partly depend on the environment for cues which may guide him in his estimates. By changing these cues we may expect to change the relation between the objective and subjective second. Thus the question to be answered is, which external cues does the subject make use of when estimating seconds? In other words: on which cues does he depend when estimating the amount of mental content?

We shall approach the problem by studying effects of *amount of change* in the stimulus background and effects of *intensity* of the background stimulation. In both cases we may expect to influence the subject's general frame of reference (i.e. the cues he makes use of for his estimates), in the former case by altering the *rate of flow of mental events*, in the latter case by changing the *intensity of an otherwise constant perception.*

We know from the experiment described in the previous section that time perception varied with the degree of mental alertness, a result consistent with our assumption that the amount of mental content per objective time unit influences its subjective duration. However, the concept of mental content is broad and vague and so far we have not attempted to specify which aspects of it are responsible for changes in subjective time: the rate of flow of separate events, the intensity of one and the same perception, or both. Presumably the main effect of the drugs was on the rate of flow of mental events. By variations in external conditions we will be able to study separately effects of rapidity of events, on the one hand, and intensity of stimulation, on the other.

The question to be answered may be specified as follows: is the perception of time influenced by the amount of separate events in the background and/or by the intensity of one and the same background stimulus? Experiments 6 and 7 deal with effects of amount of change and Experiment 8 with effects of intensity of background stimulation. Finally, effects of the

intensity of the stimulus filling the time period, as distinct from the intensity of the background stimulus, will be examined in Experiment 9.

Experiment 6: Effects of amount of change in the stimulus background. A

It is well known that when trying to assess the duration of longer time periods in retrospect, the number of events that have occupied the time period will serve as cues for the estimate: a period comprising several separate events will seem longer than equal periods filled with monotonous activity. It seems likely that similar mechanisms operate when 1-second periods are estimated in that the frequency of external events will change the frame of reference, or the cues, on which one depends for the estimate.

Similar considerations presumably underlie the opinion stated by previous investigators (e.g. James, 1890, p. 620; Fraisse, 1957) that the perception of change is the major determinant of the perception of time. However, it seems that these claims have not been experimentally examined.

We assume that a *changing stimulus* will be utilized as a cue in the estimation of seconds. Furthermore, we expect that an increase in the amount of change in the stimulus background will bring about an increase in the amount of mental events. In the experiment to be described the amount of change was varied with the aid of a metronome beating at various frequencies. On the basis of Hypothesis II it was predicted that the objective second would seem subjectively longer when the metronome was beating at a fast rate than when it was beating at a slow rate. There seemed no particular reason to expect retention of time to differ markedly under the two experimental conditions.

Procedure

Ten subjects were examined by the PPT method. Each subject took part in one experimental session which comprised two

sets of trials with the metronome beating rapidly (92 beats per minute) and two sets of trials with the metronome beating slowly (42 beats per minute). Possible effects related to order of presentation were counterbalanced by rotation. Four estimates of each duration under each of the two experimental conditions were obtained from each subject. The standard durations were 13, 25, 42, 55 and 72 seconds.

It was pointed out to the subjects that the metronome beats would not aid them in their task to read digits at a rate of one per second, but that the metronome was introduced rather as a disturbing background. Several preliminary trials with the metronome beating at various frequencies were given in order to make it clear to the subject that it was not possible to adjust the reading speed to the speed of the beats.

Results

Means of the ten individual mean scores for present, past and retained time under the two experimental conditions are shown in Table 10.

The table shows (a) that present-time estimates were consistently larger when the metronome was beating at a fast rate than when it was beating at a slow rate, (b) that past-time

TABLE 10. *Present, past and retained time under conditions of rapid (92/min.) and slow (42/min.) beating of a metronome.*

Obj. time in sec. ...	13	25	41	55	72
Present time in subj. sec.					
92/min.	14.08	25.50	40.85	54.80	71.43
42/min.	12.83	23.73	38.50	51.78	67.85
Past time in subj. sec.					
92/min.	11.73	19.38	30.18	40.93	51.88
42/min.	10.78	18.10	28.68	37.23	50.13
(Past time)/(Present time)					
92/min.	0.8634	0.7937	0.7586	0.7467	0.7330
42/min.	0.8799	0.7901	0.7516	0.7186	0.7339

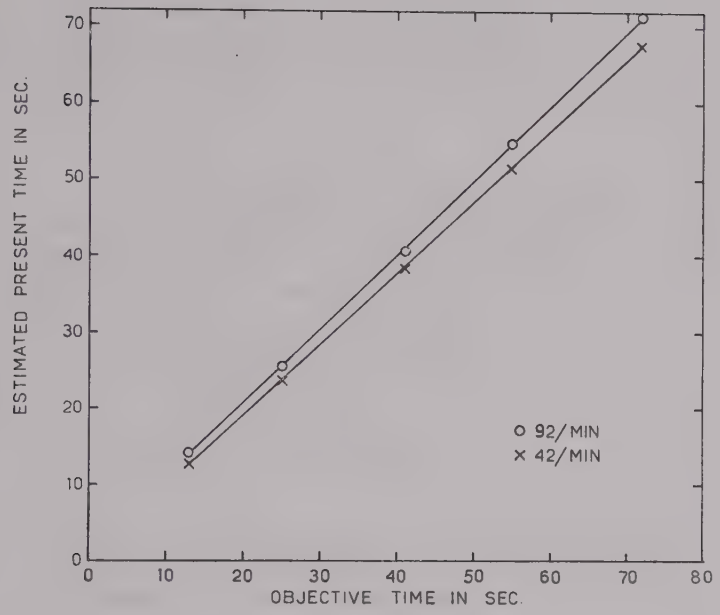

FIG. 6. Present-time estimates as affected by metronome beats of various frequencies.

estimates showed a similar trend but (c) that scores for retained time under the two conditions did not differ systematically. It is also seen that past-time estimates were consistently smaller than the corresponding present-time estimates. The difference between present-time estimates under the two conditions is illustrated graphically in Fig. 6.

Total scores for the five standard durations were calculated as described previously (see Experiment 5) and the intra-pair mean differences between scores from the two experimental conditions were submitted to *t*-tests.

The differences in present-time estimates were significant beyond the 0.01 level ($t=3.357$, $df=9$). Since the differences obtained were in the predicted direction, the test in this case is one-tailed. The differences in past-time estimates did not reach significance ($t=1.584$, $P>0.10$), and the differences in retained time were negligible ($t=0.125$).

Thus the results are consistent with Hypothesis II. When the amount of mental events is increased, the objective second becomes subjectively longer.

Comment

It may be argued that the differences is present-time estimates obtained with fast versus slow metronome beats were not related to variations in the amount of mental events, but to a tendency to synchronize the reading with the beats. In this case the effect produced by the metronome rates would not necessarily reflect a change in time experience but possibly merely a change in reading speed. If this were the case we would expect the subjects either to follow the metronome rhythms as such, or to adjust the speed of reading digits to one at every second beat, two at each beat or some such simple pattern. However, the individual records offer no support for this assumption. Nevertheless, a special experiment was designed as a further test on the effect of change in the stimulus background on the perception of seconds.

Experiment 7: Effects of amount of change in the stimulus background. B

In this experiment irregularly recurring auditory signals were used to increase the amount of change in the stimulus background. The irregularity of the signals served to eliminate a possible synchronization of reading speed with the stimuli. It was predicted that the objective second would seem subjectively longer when the auditory stimuli were introduced in the background.

Procedure

Auditory signals (500 c.p.s.) were recorded on magnetic tape. The duration of signals and of empty intervals was irregular and random as shown in the sample presented in Fig. 7. The signals were presented to the subject through earphones.

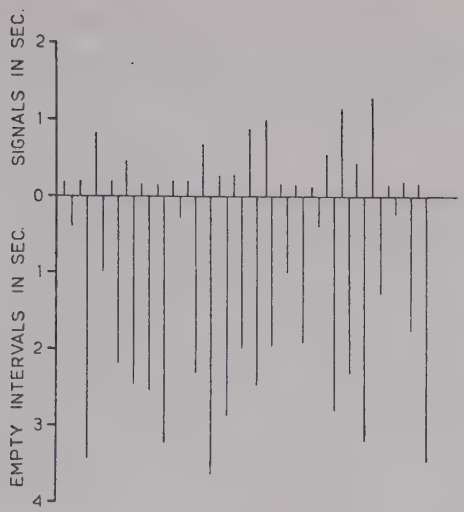

FIG. 7. A 1-min. sample of the stimulus pattern. (Total time of signals 10 sec. and of empty intervals 50 sec.)

Ten subjects participated in the experiment. Since, in this case, we were interested in present-time estimates only, the PPT method was replaced by the method of tapping at an estimated speed of 1 per second. The taps were recorded by an electric counter and the time taken to complete 30 taps was measured by a stop-watch to the nearest 0.5 second.

Each subject came to one session which comprised two sets of 2 trials each with auditory stimulation and two sets of 2 control trials (i.e. trials without auditory stimulation). Possible effects related to order of presentation were counterbalanced by rotation. The score was the mean *objective* time taken to complete 30 taps in the four trials under each experimental condition, respectively.

Results

The results are summarized in Table 11. It is seen that the mean objective time taken to complete 30 1-second estimates was shorter when the auditory stimulation was introduced than

TABLE 11. *Objective time in sec. taken to complete 30 taps with an estimated speed of 1/sec. under conditions of auditory stimulation and under control conditions.*

Means				
Control	Aud. stim.	$M_{diff.}$	S.D. of diff.	t
32.39	30.93	1.463	1.208	3.632

under control conditions. Thus the objective second seemed subjectively longer when the amount of stimulation was increased. The subjective length of 1 objective second was 0.970 seconds under conditions of auditory stimulation compared with 0.926 seconds in the control situation.

Intra-pair mean differences between scores obtained under the two conditions were submitted to the t-test. Since a difference in the predicted direction was obtained, the test is one-tailed. The difference was significant beyond the 0.01 level.

The results support Hypothesis II in showing that the objective second became subjectively longer when the amount of mental events was increased by an increase in the amount of external stimulation.

EXPERIMENT 8: EFFECTS OF INTENSITY OF THE STIMULUS BACKGROUND

The aim of this experiment was to study effects of variations in intensity of an auditory background on perception of time. In so far as an increase in intensity brings about an increase in mental content, we may, on the basis of Hypothesis II, expect the objective second to seem subjectively longer when intensity is increased. However, we have stressed that an external stimulus, in order to affect 1-second estimates must alter the environmental cues which serve as a frame of reference for the subject. The assumption that a stimulus background would be effective,

which contained a greater or lesser amount of change, was verified in the two previous experiments. We shall now consider time estimation as affected by variations in intensity of stimulus background, when such cues as provided by intermittent stimuli are lacking.

Hirsh, Bilger & Deatherage (1956) demonstrated an influence of auditory background on reproduction of time intervals. They found that reproductions made in noise of stimuli presented in quiet were longer than reproductions made in quiet of stimuli presented in noise. Changes in visual background had no noticeable effect on reproductions. These findings, however, have no direct bearing upon our problem, nor does there seem to be any other experiments focussed on the question of effects of intensity of stimulus background on time estimation.

Procedure

Fifteen subjects were examined by the PPT method. The subjects wore earphones connected to a tone generator which delivered a continuous tone of 500 c.p.s. Estimates were obtained under 3 different conditions of background stimulation: (a) a tone of high intensity, (b) a tone of low intensity, and (c) no auditory stimulation. The three experimental conditions were rotated so as to counterbalance possible effects of order of presentation. Each subject gave 4 estimates of each standard duration under each of the three conditions. The standard durations used were 12, 21, 32, 42 and 53 seconds.

The choice of stimulus intensities was determined in preliminary trials and may be defined as follows. The high intensity stimulus is a sound the intensity of which the subject experiences as strong but definitely below the intensity experienced as unpleasant. The low intensity stimulus is a sound experienced as weak but distinctly audible without strain of attention.

Results

The means of the individual mean scores in present, past and retained time are presented in Table 12. It is seen that there are no consistent differences between scores obtained under the

TABLE 12. *Present, past and retained time as influenced by various auditory backgrounds.*

Obj. time in sec. ...	12	21	32	42	53
Present time in subj. sec.					
No sound	13.12	22.90	33.45	45.12	55.63
Low intensity sound	13.40	22.70	34.43	44.68	56.00
High intensity sound	13.37	22.78	34.45	45.28	55.67
Past time in subj. sec.					
No sound	10.20	17.08	24.65	32.35	39.65
Low intensity sound	10.65	16.92	24.37	31.87	38.82
High intensity sound	9.93	17.00	25.15	30.80	40.15
(Past time)/(Present time)					
No sound	0.8095	0.7651	0.7355	0.7370	0.7589
Low intensity sound	0.8383	0.7771	0.7394	0.7409	0.7271
High intensity sound	0.7721	0.7688	0.7591	0.7075	0.7414

three different conditions. We may thus conclude that the intensity of the auditory background did not affect the relation between the objective and subjective second, nor was the retention of time influenced by the background stimulations employed.

EXPERIMENT 9: EFFECTS OF INTENSITY OF THE STIMULUS CONTENT

Though the intensity of the auditory background did not affect time estimation, the intensity of an auditory stimulus filling the time period to be estimated may exert an influence on the seeming duration. In other words, instead of altering the *background* against which time is perceived, we may alter the *content* of the interval to be estimated.

Results obtained by previous investigators on effects of stimulus intensity on time estimation are conflicting. Oléron (1952) worked with reproduction of brief auditory signals (below 1.5 sec.) of 3 different intensities. She concluded that an increase in the intensity made the time period seem longer. Lifshitz (1936)

arrived at the same conclusion, whereas Hormia (1956) obtained opposite results. He constructed subjective scales for intensity for different sensory modalities and investigated variations in productions of 10-second periods as related to the subjective intensity of the stimulus. A tendency was found for productions to become longer with increased intensity and the author concluded that an increase in stimulus intensity made the time seem shorter. It is possible that the difference in results from the various experiments is associated with variations in the length of the time periods employed, in that intensity exerts a reverse influence on perception of time, on the one hand, and retention of time, on the other. No previous attempt seems to have been made to examine directly the influence of intensity on the relation between the objective and subjective second.

Goldstone, Boardman & Lhamon (1958 *c*) compared estimates of 1-second intervals filled with auditory and visual stimuli. It was shown that one subjective "visual second" occupied significantly more objective time (1.02 seconds) than one subjective "auditory second" (0.59 seconds). These experiments were performed with the method of limits. It seemed possible that measurements by a similar technique would reveal a difference in the subjective duration of intervals filled with auditory stimuli of various intensities. If a more intense stimulus causes an increase in mental content, we may, on the basis of Hypothesis II, expect the objective second to be subjectively longer when filled with an intense stimulus than when filled with a weak stimulus.

Procedure

Twenty subjects participated in the experiments, which were carried out by the up-and-down method (cf. Guilford, 1954, pp. 114–115). Preliminary experiments indicated that this method gave essentially the same results as the method of limits and the up-and-down method was chosen because of its greater convenience. There were two experimental conditions, one in which weak and one in which strong auditory stimuli were employed. (The definition of weak and strong stimuli is the same as that used in Experiment 8.)

A motor-driven commutator was used to produce auditory signals, which could be varied in duration from 0.2 to 4.0 seconds by 0.1 second steps. The subject was instructed to judge whether the stimulus presented by the experimenter was more or less than 1 second. If the answer was "more", the next stimulus presented was one step lower, i.e. 0.1 second shorter, and if the answer was "less", the next stimulus was one step higher. The initial stimulus in each series was always 1.0 objective second. Every time there was a change in judgment from more to less or vice versa the threshold was registered as the midpoint between the stimulus yielding the answer "more" and the stimulus yielding the answer "less". This point gave the objective length of the subjective second. One experimental session comprised four sets of trials, two with high intensity and two with low intensity stimuli. The two conditions were rotated. Ten threshold determinations were obtained from each subject under each condition in one session, and every subject came for two sessions.

Results

The objective length of the subjective second under each of the two conditions was determined for each subject by calculating the means of the thresholds obtained. The means of the 20 individual means were calculated. It was found that the subjective second under the high intensity condition equalled 0.904 objective seconds and under the low intensity condition 0.916 objective seconds. The *t*-value based on intra-pair mean differences was 0.783. In other words, the intensity of the stimulus filling the interval had no marked influence on its subjective duration.

Summary of experiments 6 to 9

The aim of the experiments described in this section was to investigate effects of changes in external stimulus conditions on the relation between the objective and subjective second. It was stated at the outset that only such external conditions would

exert an influence on this relation as affected those aspects of the mental content which serve as cues for the estimation of seconds.

It was argued that the general concept of amount of mental content could be split up into two components: (a) the perceived rate of separate events and (b) the perceived intensity of one and the same event. Experiments were carried out in which these two aspects of mental content could be studied separately.

Effects of the *stimulus background* were studied (a) by varying the *amount of change* as provided by intermittent auditory stimuli and (b) by varying the intensity of a constant auditory stimulus. It was shown that the objective second was subjectively longer when the amount of change was increased, whereas no effect of the intensity of the background stimulus was seen.

Effects of intensity were examined further by varying the *intensity of the stimulus content*, as distinct from the stimulus background. Not even in this case did the intensity have any marked effect on the apparent duration of the stimulus.

The general conclusions to be drawn from these experiments are that the rate of flow of mental events will influence the perception of time, whereas no support has been obtained for the assumption that the intensity of a constant stimulus would affect time perception. The results of these experiments are in good agreement with those obtained by drug-induced changes in mental alertness, since a change in mental alertness presumably implies a change in the rate of flow of mental events rather than in intensity of perception.

Consequently the concept of amount of mental content as used in Hypothesis II may be substituted by the more restricted concept of amount of mental events, which refers to the rate of flow of mental processes. With this re-formulation of the hypothesis we may conclude that it was supported by the above experiments, which showed that the objective second became subjectively longer when the amount of mental events was increased.

CHAPTER VIII

RETENTION OF TIME AS INFLUENCED BY VARIATIONS IN EXTERNAL CONDITIONS

The general assumption that the retention of passed time intervals is related to the amount retained of the events filling this interval was supported in experiments 1 to 4, which showed (a) that past-time estimates were always smaller than the sum of the present-time estimates on which they were based and (b) that retention of amount of time and amount of stimulus material perceived within this interval followed the same general trend. Further support for this assumption was obtained in Experiment 5, where it was shown that the difference between the time perceived and retained decreased when the internal conditions favoured retention processes (increased mental alertness) and increased when internal conditions impeded retention (decreased mental alertness).

The aim of the experiments to be reported next was to examine retention of time as influenced by external conditions, which could be assumed to impair or improve retention. It is well known from learning experiments that retention may be improved when environmental factors serve to focus the subject's *attention* on the task. Other conditions of importance for retention are *similarity versus dissimilarity* of successive events. We shall examine the retention of time under conditions of increased attention as brought about by the use of an electric shock (Experiment 10) and under conditions of more or less similarity between the events filling the time period (Experiment 11).

Experiment 10: Effects of electric shock

The aim of this experiment was to compare time estimates given when the intervals to be estimated were terminated by an electric shock with estimates given under control conditions.

Increased attention is known to affect learning and retention favourably. It was argued that waiting for the shock would give rise to a more intense awareness of the time units in passing, causing individual seconds to be more acutely memorized and thus better retained. On the basis of Hypothesis III it was predicted that scores for retained time would be larger under shock conditions than under control conditions.

Since the interpolated activity was the same under shock and control conditions, no differential effect on perception of time was expected to occur (Hypothesis II). On the basis of Hypothesis I past-time estimates were expected to be smaller than the corresponding present-time estimates under both experimental conditions.

Procedure

Ten subjects were examined by the PPT method. Each subject took part in one experimental session, which comprised two sets of shock trials and two sets of control trials. Possible effects related to order of presentation were counterbalanced by rotation. Four estimates of each standard duration were obtained from each subject. The standard durations were 13, 25, 41, 55 and 72 seconds.

The ready signal, a clicking sound, for each duration to be estimated was the same in the shock and control situation. In the control situation the stop signal was identical with the ready signal. In the shock situation an electric shock applied to the ulnar nerve at the elbow for about 0.5 second served as a stop signal. The current produced a muscle contraction and a sensation of unpleasantness rather than distinct pain. The experimental trials were preceded by three preliminary trials with and three without shock.

TABLE 13. *Present, past and retained time under electric shock and control conditions.*

Obj. time in sec. ...	13	25	41	55	72
Present time in subj. sec.					
Shock	10.75	20.25	33.25	43.83	57.48
Control	11.08	20.68	33.15	44.70	58.90
Past time in subj. sec.					
Shock	10.23	18.35	27.93	37.25	51.50
Control	8.83	15.95	25.65	34.08	44.48
(Past time)/(Present time)					
Shock	0.9801	0.9389	0.8889	0.8964	0.9474
Control	0.8046	0.8010	0.8224	0.8183	0.8094

Results

Means of the ten individual mean scores for present, past and retained time, respectively, under the two experimental conditions are shown in Table 13.

The table shows (a) that past-time estimates were consistently smaller than the corresponding present-time estimates, (b) that present-time estimates did not differ markedly under the two experimental conditions, whereas (c) past-time scores were consistently larger in the shock situation, and (d) that, similarly, scores for retained time were consistently larger in the shock situation. The differences in retained time are illustrated graphically in Fig. 8.

Total scores for the five standard durations were calculated as described previously (see Experiment 5) and the mean intra-pair differences between scores from the two experimental conditions were submitted to *t*-tests.

The differences between scores for retained time were significant at the 0.02 level ($t = 2.357$, $df = 9$). Since a directional prediction was made, the test in this case is one-tailed. Present- and past-time scores did not differ significantly under the two conditions.

Thus the results obtained were consistent with Hypothesis III

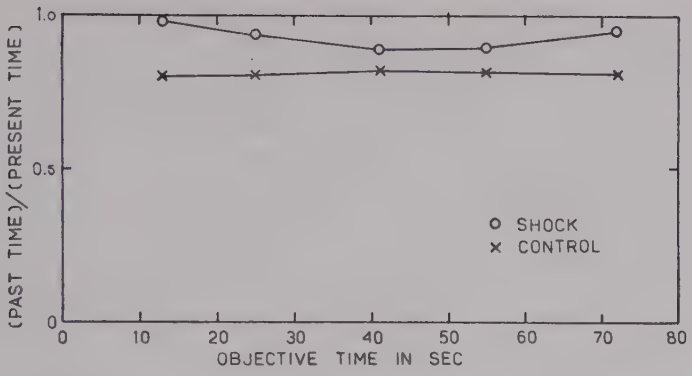

FIG. 8. Quotients for retained time as affected by electric shock.

in showing that, under conditions which favoured retention, more was retained of an elapsed time period. In other words, the discrepancy between time perceived and retained decreased when conditions favoured retention.

Measures of variability are shown in the Appendix, Tables V and VI.

Comment

The relatively mild electric shock used did not seem to evoke anxiety though all subjects considered it an unpleasant experience. The degree of unpleasantness experienced varied considerably among subjects according to introspective accounts and observations of the subjects' general behaviour. Since physiological reactions—galvanic skin response, pulse rate, etc. —were not recorded, no attempt was made to correlate effects on time estimates with other effects of the shock.

The results of this experiment are consistent with the well-known experience that a time period spent in anticipation seems long. This common observation is here interpreted in terms of an increase in amount of events retained under conditions of sustained attention.

The results are in general agreement with those obtained by Falk & Bindra (1954) in an experiment on effects of electric shock on time estimation. They found shorter productions of

15-second intervals in an experimental group which, in half of the trials, received a shock at the termination of the productions compared with a control group, where no shock was given. (It should be noted that shorter productions correspond to larger past-time scores as obtained by the method of estimation of elapsed time.) The results, however, were somewhat ambiguous, since the subjects in the experimental group gave shorter productions than the control subjects, whether the productions were terminated by a shock or by a sound (in half of the trials), as indicated to the subject by a red versus blue signal switched on during the production. This lack of difference between shock and control trials *within* the experimental group was considered a consequence of the subjects not discriminating motivationally between shock and non-shock trials in the shock situation. The main result, i.e. that productions in the experimental group were significantly shorter than in the control group, the former being also objectively more accurate, was interpreted in terms of "the more anxious *set* induced by shock". The possibility that an increased "vigilance" was responsible for the greater accuracy of the estimates in the shock group was discussed but not considered satisfactory.

According to our point of view "an anxious set" does not in itself explain a difference in time estimation, whereas if it is accompanied by a sharpening of attention and improvement in retention, the latter may be used as explanatory concepts.

Summary

Estimates of time intervals terminated by an electric shock were compared with estimates under control conditions. It was argued that waiting for the electric shock would favour retention of past time because of a more acute memorizing of the time units in passing.

The results obtained showed that scores for retained time were considerably larger under shock conditions. These results are consistent with Hypothesis III in showing that more is retained of the time units perceived, when the conditions favour retention.

Experiment 11: Effects of similarity between events

It is well known from learning experiments that the degree of similarity between successive items in a list may exert a marked influence on the results, learning being usually facilitated when similarity is decreased. Gibson (1940, 1942) tried to account for this phenomenon in terms of *discrimination versus generalization* of stimulus items. According to her hypothesis, which was supported by experimental evidence, low intra-list similarity favours discrimination between items and, hence, facilitates both learning and retention.

On the basis of our general assumption that the retention of an elapsed time period varies with the retention of the events filling this period, it was argued that the degree of similarity between successive events should exert an influence also on the retrospective estimate of the time period. It was assumed that less would be retained of a time period filled with similar events than of an objectively equal period filled with dissimilar events. In other words, time would seem shorter in retrospect when filled with similar events. These general considerations served as a basis for the experimental approach.

Two preliminary experiments were performed in which the degree of similarity between successive visual items was varied. In the main experiment a wider range of similarity–dissimilarity was employed. Situations were arranged where the subject performed two tasks, either singly or alternately for a given period of time. It was argued that if retention of time is related to the retention of the events filling the time period, a given objective duration should seem shorter when filled with only one type of activity than when filled with two types.

Preliminary experiment 1

Six subjects were examined by the PPT method. The list of digits ordinarily used was supplemented by two other lists, one of which contained consonants only, and one in which digits and consonants were mingled. According to the assumption that less similarity favours retention, scores for retained time should be larger on the mingled list.

However, no difference was found between time estimates of periods filled with these two types of material.

The most probable explanation is that the conditions did not provide a sufficient degree of dissimilarity, digits and consonants being too alike. The results are consistent with those obtained in analogous memory studies. Attempts to increase the memory span by using series of mingled digits and consonants instead of digits only have not been successful. These negative results have been interpreted in terms of insufficient degree of dissimilarity between digits and consonants (e.g. Harden, 1929).

Preliminary experiment 2

Twelve subjects were examined by the PPT method. Three different lists were used. One list contained series of the words "red", "blue" and "green" arranged in random order. In another list the words were substituted by circles coloured red, blue and green. The third list contained words and circles randomly mingled with one another. It was argued that more should be retained of the time period spent on the mingled list where similarity between items was less. This assumption, however, was not supported by the results.

This negative result may be associated with an increase in the degree of difficulty that the subjects clearly experienced when occupied by reading colour words and naming the colour of circles alternately. Previous investigations (Harton, 1938 *a*, *b*) have shown that the time spent at difficult tasks is estimated as shorter, in retrospect, than time spent at easy activities. Hence it is possible that effects of decreased similarity were outweighed by effects of increased difficulty.

Contrary to expectation, a statistically significant difference was found between scores for retained time on the list of words and the list of circles ($P \sim 0.02$). A possible explanation of this difference is that in the list of circles successive items tended to blur together, whereas in the list of words successive items were more distinctly separate. This greater "isolation" of successive words may have favoured retention. This, however, is an *ad hoc* explanation.

Procedure

The main experiment consisted of three parts: (A) a visual and auditory signal task, (B) a left- and right-hand tapping task, and (C) a multiplication and writing task. Each part of the experiment was performed under three conditions, two of which represented conditions of similarity and one a condition of dis-

similarity. Parts (A) and (B) were modelled on procedures used by Nagge (1935) in experiments on associative interference.

A: SIGNALS.—A motor-driven commutator enabling subjects to adjust the rate of visual and auditory signals was used. The auditory signals were presented to the subjects through earphones, and the visual signals by a bulb in the centre of a white metal screen placed at eye level about 1 metre from the subject. The experimenter could switch on and off at will the circuits to the earphones and bulb, and could also adjust the rates of the signals.

The subjects were given instructions to adjust the signals by means of a lever to a rate that seemed agreeable—their personal tempo. This was repeated 3 to 4 times within each period. Preliminary trials were given to allow the subject to find his personal tempo and become accustomed to the procedure.

The task was divided into the following three parts:

(1) Visual signals only (V)

(2) Auditory signals only (A)

(3) Visual and auditory signals alternately (V A)

(1) and (2) represent conditions of similarity and (3) a condition of dissimilarity. At the end of each sub-task the subjects were asked to estimate the length of the time spent at the task. As in the other parts of the experiment, instructions were given to refrain from counting and making use of other possible cues during the actual performance; the subjects were to rely on their immediate impressions and give a spontaneous judgment.

The total time spent at the task under each condition was 4 min. and 15 sec. (255 sec.). This period was divided into four 1-minute periods with a 5-second pause between them. The scores for each subject were the means of his estimates in four trials under each condition.

B: TAPPING.—The subjects were instructed to tap at an agreeable rate—again their personal tempo. Preliminary trials were given for both hands, so that the most comfortable position and rate were found. The task was divided into three parts by varying the conditions as follows:

(1) Right hand only (R)
(2) Left hand only (L)
(3) Right and left hands alternately (R L)

(1) and (2) represent conditions of similarity and (3) a condition of dissimilarity. After each sub-task the subjects stated how long time they thought they had spent.

The total time for each of the above parts was 1 min. 50 sec. (110 sec.) divided into six periods of 15 seconds with a 4-second pause between each. The scores for each subject were the means of his estimates in four trials under each condition.

C: Multiplication-Writing.—The two tasks of this experiment were to multiply 1×2 digit items and to write a special figure. Multiplication was performed as a paper-and-pencil test with items arranged in order of difficulty. The subjects were instructed to perform rapidly, but with a certain degree of care. The other task entailed writing the figure S 2 at a steady pace, but at the same time in an orderly and symmetrical manner. The three parts of the task were:

(1) Multiplication only (M)
(2) Writing only (W)
(3) Multiplication and writing (M W)

Under the condition of dissimilarity (3) the subjects started by multiplying, and at half time were told to start writing immediately.

The total time for each condition of the task was 2 min. 30 sec. (150 sec.). The scores for each subject were his mean estimates in four trials under each condition. (Because of a mishap in the Tapping task it was necessary for the first six subjects to return twice and repeat this task. At the same time additional estimates were obtained of the Multiplication–Writing task. Thus eight estimates were obtained for six subjects.)

Design.—Twelve subjects participated in the experiment. Each subject came for two sessions. In one session each task was performed twice.

The nine sub-tasks were rotated according to the pattern: abc–bca–cab, run through both forwards and backwards at each

session. The three conditions of dissimilarity were evenly spaced as Nos. 2–5–8 in the series of nine sub-tasks. A short rest was inserted before running backwards through the series.

Results

The main results of the experiments are summarized in Table 14. Each time score constitutes the mean of the twelve individual means. The (S) column gives the average of the two sets of scores obtained under conditions of similarity.

TABLE 14. *Time estimates under conditions of similarity (S) and dissimilarity (D).*

Task	Obj. time in sec.	Mean estimate in sec. S	Mean estimate in sec. D	Increase in per cent
Signals	255	234.17	267.92	14.41
Tapping	110	135.12	140.58	4.05
Multiplication–Writing	150	149.24	162.75	9.05

Inspection of the mean estimates listed in the table shows that a given objective duration was estimated as longer under conditions of dissimilarity than under conditions of similarity between events. The increase varies between about 4 and 14 per cent. These results are consistent with the prediction based upon Hypothesis III.

The mean intra-pair differences of the similarity and dissimilarity scores were submitted to one-tailed t-tests. In the Signal and Multiplication–Writing tasks the differences were significant (Signals: $t=3.109$, $P<0.01$, $df=11$; Multiplication–Writing: $t=2.356$, $P<0.05$, $df=11$). In the Tapping task the differences, though in the expected direction, did not reach statistical significance ($t=1.304$, $P\sim0.10$).

Estimates given under the two conditions of similarity of each task were also examined separately. The 255-second interval was estimated

as shorter when filled with visual signals (225.4 sec.) than when filled with auditory signals (242.9 sec.). The 150-second interval was estimated as shorter when spent in multiplying (145.3 sec.) than when spent in writing (153.2 sec.). There was no marked difference between estimates of the 110-second interval spent in tapping with right versus left hands (133.6 and 136.7 sec.).

Possible systematic changes at consecutive trials were examined by comparing the mean scores of the 12 subjects on the first and second trial of each task. No uniform tendency toward longer or shorter estimates as the session progressed was found.

Comment

The results of this experiment are consistent with the everyday experience that, when considered in retrospect, a time period filled with varied activities usually seems longer than an equal period spent under monotonous conditions. However, the interpretation of this phenomenon is open to question.

The present experimental approach was based on the assumption that a certain resemblance may exist between the effects of similarity of stimulus material on retention in learning experiments, on the one hand, and on retention of time intervals, on the other. It was argued that less would be retained of a time interval filled with one type of activity only, as compared with a time interval filled with two types, since interference effects would be greater in the former case. In other words, time would seem shorter when filled with one type of activity only.

The results obtained were consistent with this prediction. However, the differences between our experiments on time and conventional learning experiments are obvious. In particular it should be noted that the question has not been settled, whether degree of intra-list similarity affects both aspects of the learning process, i.e. acquisition and retention. Whereas there is considerable evidence to show that similarity influences learning in general, effects on retention have been debated (e.g. Underwood, 1953). In our experiments on time, however, we have no reason to expect *perception* of time to differ under conditions of similarity and dissimilarity. Hence the entire difference in time estimates may be ascribed to differences in retention, in the

operational sense in which the term is used in this investigation.

Because of the discrepancy between learning experiments and the present experiment it is possible that different mechanisms are responsible for the results. If this were the case the resemblance between the results obtained in these two types of experiments could be somewhat superficial. At least it seems necessary to take into account the possibility that our results may be influenced by factors other than interference as operating in experiments on learning of similar items. As an alternative explanation we may mention the possibility that the greater variety experienced under conditions of dissimilarity increased mental alertness which, in turn, resulted in better retention.

When, as was the case in this experiment, retention of time is measured by the method of verbal estimation of elapsed time, we do not have the perception of present time under control. Only by using the PPT method is it possible to determine with certainty whether a change in time estimation is caused by a change in retention or perception of time. Thus, we do not know whether the differences obtained in estimates of periods filled with, for example, visual, as compared with auditory, signals were related to differences in amount of mental content affecting perception rather than retention of time. However, our conclusions are based on a comparison between means of the estimates obtained under the two conditions of similarity and the estimates under the condition of dissimilarity. Consequently a possible difference between the two conditions of similarity in respect of perception of time is of minor importance.

However, it could be assumed that perception of time was affected by the change from one type of activity to another under the condition of dissimilarity. If this were the case, the differences in time estimates obtained could be due to differences in perception rather than retention of time. However, as pointed out above, this explanation is rather far-fetched for the present data. A rapid alternation between activities is likely to increase the amount of mental events per objective time unit and thereby affect perception of time (see Experiments 6 and 7).

But in the case of the Signal task there was a 65-second period between each exchange of auditory and visual signals and in the Multiplication-Writing task 75 seconds were spent at each of the two activities. Under these conditions it seems highly improbable that a change in stimulus conditions would exert an influence on the perception of present time and we may conclude that the differences in time estimation obtained were, in this case, caused by changes in retention.

The present experiment bears certain resemblances to Harton's (1939 *a*, 1942) experiments on effects of "unity of organization" on time estimation. He showed that time periods spent in activities involving one definite goal were experienced as shorter than equal periods spent in activities with several goals. It may be assumed that an activity where the subject is striving towards one goal involves more similarity between successive events than an activity with several goals. Thus it would seem that Harton's results may also be interpreted in terms of differences in retention as determined by the filling of the time period.

In the tapping task the difference between time estimates under conditions of similarity versus dissimilarity was comparatively small. A likely explanation of this is that tapping with right and left hand was not sufficiently dissimilar to cause a marked difference in retention processes when performed alternately. As pointed out earlier, the failure in some memory studies to demonstrate effects of variations in inhibitory influences in the learning material has been ascribed to insufficient dissimilarity between items. Similarly, Harton (1939 *a*) points out that one of the factors complicating experimental tests of his hypothesis was making the two types of tasks (with one versus several goals) sufficiently dissimilar for the subject to experience a change in unity of effort when passing from one type of activity to the other.

The results of this experiment suggest that some of the problems of time estimation may be fruitfully approached by methods parallel to those used in memory studies, though no previous attempts of this nature seem to have been made.

Summary

Time estimation was studied under conditions providing various degrees of similarity between successive events.

Situations were arranged where the subjects performed two tasks, either one at a time or alternately, for equal objective time periods. Since a high degree of similarity between successive items usually has a detrimental effect on learning processes, it was predicted that the time periods would seem shorter when filled with only one type of activity than when filled with two types. In the latter case the amount of interference would be smaller and thus more would be retained of the time experienced within this period.

The results obtained agreed with the prediction and thus supported Hypothesis III in showing that more was retained of the time experienced under conditions which favoured retention.

CHAPTER IX

TIME ESTIMATION AS AFFECTED BY CERTAIN DRUGS

In contrast to all the experiments described in the previous sections, those to follow were not performed with the aim of testing our hypotheses. The aim of these experiments was to examine effects of some drugs, *caffeine*, *quinine* and *nitrous oxide*, reported by previous investigators to affect time estimation. Since the results of these earlier investigations have been either contradictory or inconclusive, an attempt was made to analyse effects of these drugs more closely with the PPT method. In some cases the information gained in the experiments described in previous sections made it possible to predict changes in a certain direction, but on the whole these experiments were purely exploratory and were carried out merely to secure more information about the presumed effects of these drugs on time estimation.

Experiment 12: Effects of quinine and caffeine

The aim of this experiment was to study effects of quinine and caffeine on time estimation.

Grabensberger (1933) claimed the normal "time sense" in ants to be markedly altered by quinine. Ants were trained to be fed at a given place at definite time intervals. After the animals had been fed with quinine, the established habits were disorganized and they came about three hours later than expected to the feeding place. Thyroxine was claimed to have a reverse

effect on time habits. Similar results were obtained with other insects (Grabensberger, 1934). However, Grabensberger's results have been questioned by Renner (1957) who failed to demonstrate an effect of quinine and thyroxine on the time sense in bees.

Sterzinger (1935, 1938) studied the effects of quinine on time estimation in humans. Thyroxine, caffeine and alcohol were also tried. The following method was used. The examiner trained subjects, one at a time, to estimate a given period of time by sounding a bell when this period had elapsed. Following this, the subjects were asked to mark off the requested periods themselves until the examiner considered that they had mastered the task. The next step was to administer the drug and have the subject perform the same task.

Sterzinger concludes that objective time was estimated as shorter after the intake of quinine: when marking the time periods, the subjects allowed an objectively longer period to elapse than under normal conditions. However, the results were highly inconsistent. Sterzinger tried to account for the inconsistencies by assuming a "reversal" in respect of effects of quinine on time estimation. Thus intervals of more than 5 objective minutes were assumed to become subjectively shorter and intervals of less than 5 minutes subjectively longer under the influence of quinine compared with normal conditions. The point of reversal was assumed to vary considerably among individuals, being 2 to 3 minutes rather than 5 for some subjects.

It is difficult to find conclusive evidence for this claim in the data presented by Sterzinger. Examination of the eight individual records presented in his two studies shows that estimates of 15-minute and 5-second intervals constantly demanded more objective time under quinine, whereas estimates of 1–8 minutes did not follow any consistent pattern. Since all subjects were given either different doses of quinine, different occupations during the intervals or intervals of different length, the results are not easy to assess. Nor can practice effects be evaluated since, in most cases, control experiments always preceded drug experiments. Consequently it is not possible to determine if the lack

of consistency as to the effects of quinine was related to the length of the time period or if different subjects reacted differently or, finally, if the differences observed were merely due to chance.

Clauser (1954, pp. 46–47) also claims to have found evidence for an effect of quinine on time estimation in humans. However, only data from a single experiment on one subject are reported and the results are too inconsistent to permit any conclusion, especially as no adequate control data are presented.

Sterzinger claimed that thyroxine produced changes opposite to those of quinine. The effects of both these drugs were ascribed to changes in cell metabolism. Alcohol was found to produce effects similar to those of quinine. Caffeine, on the other hand, produced effects similar to those of thyroxine in one subject, but had no noticeable effect in two other subjects. The effects of caffeine and alcohol were ascribed to changes in the activity of the nervous system. This distinction between effects on cell metabolism and the nervous system does not seem justified. Neither did the experimental design provide adequate rotation of the various drugs.

However, the changes reported after intake of quinine were quite striking in some subjects and thus deserve further study. It was also thought to be of interest to examine the effects of caffeine more closely. Because caffeine should increase mental alertness, it was predicted that both estimates of present and retained time would be larger under the influence of caffeine than under control conditions. In respect of quinine it was not considered possible to make any specific predictions. As in previous experiments, past-time estimates were expected to be smaller than present-time estimates under all experimental conditions (Hypothesis I).

Procedure

General design.—Twelve subjects participated in the experiment. Each subject came to three sessions, and the experimental conditions were rotated according to the following pattern:

Subject	*First session*	*Second session*	*Third session*
1	Control	Quinine	Caffeine
2	Quinine	Caffeine	Control
3	Caffeine	Control	Quinine

etc.

This design was repeated for 12 subjects. The intervals between sessions ranged between a minimum of 2 and a maximum of 7 days.

DRUGS.—Capsules with either 500 mg quinine, 300 mg caffeine or a lactose placebo were taken by mouth 1 hour and 15 minutes before the experiments started. The amount of the administered drugs was limited by the necessity of avoiding impairment of the subjects' ability to cooperate. All capsules were identical in appearance and the subjects were not told which they received.

The subjects were allowed a light meal before they came to the experiments, which were carried out in the morning. Although no special period of rest was prescribed, none of the subjects had taken part in bodily exercise before the experiments.

EXPERIMENTS.—The subjects were examined by the *PPT method.* Ten estimates of each standard duration were obtained from each subject under each experimental condition. The standard durations used were 12, 21, 32, 42 and 53 seconds.

Personal tempo was examined by the procedure previously described (see Experiment 5). The score was the mean number of taps at four 30-second periods, two of which were performed at the beginning and two at the end of each session.

Results

Means of the 12 individual mean scores for present, past and retained time are shown in Table 15.

The table shows (a) that past-time estimates were smaller than the corresponding present-time estimates, (b) that present-time estimates obtained under caffeine were consistently largest, whereas quinine and control scores did not differ markedly,

TABLE 15. *Present, past and retained time under control, quinine and caffeine conditions.*

Obj. time in sec. ...	12	21	32	42	53
Present time in subj. sec.					
Control	12.58	22.04	32.83	43.21	53.83
Quinine	12.63	21.73	32.83	42.90	53.66
Caffeine	13.28	23.11	34.83	45.41	56.74
Past time in subj. sec.					
Control	8.63	14.79	21.52	28.39	35.86
Quinine	8.93	13.61	21.80	27.55	36.52
Caffeine	9.04	14.47	21.85	29.42	37.67
(Past time)/(Present time)					
Control	0.7153	0.7020	0.6808	0.6895	0.6984
Quinine	0.7564	0.6792	0.7137	0.6846	0.7399
Caffeine	0.7171	0.6589	0.6593	0.6790	0.7058

(c) that past-time scores also showed a slight tendency to be largest under caffeine, and (d) that scores for retained time were consistently larger under quinine than under caffeine, whereas there was no consistent difference between control scores and the two sets of drug scores. The difference between present-time estimates under caffeine and control conditions is illustrated graphically in Fig. 9.

Total scores for the five standard durations were calculated as before (see Experiment 5) and mean intra-pair differences between scores for present, past and retained time from the three experimental conditions were submitted to *t*-tests.

The difference in present-time estimates between caffeine and control scores was nearly significant at the 0.05 level ($t = 1.739$, $df = 11$; since in this case a directional prediction was made, the test is one-tailed). In the case of caffeine and quinine conditions, the difference in present time was somewhat larger ($t = 2.716$, $P \sim 0.02$). None of the differences in scores for past or retained time reached statistical significance.

Thus the results of this experiment show (a) that caffeine affected present-time estimates in the manner predicted, whereas

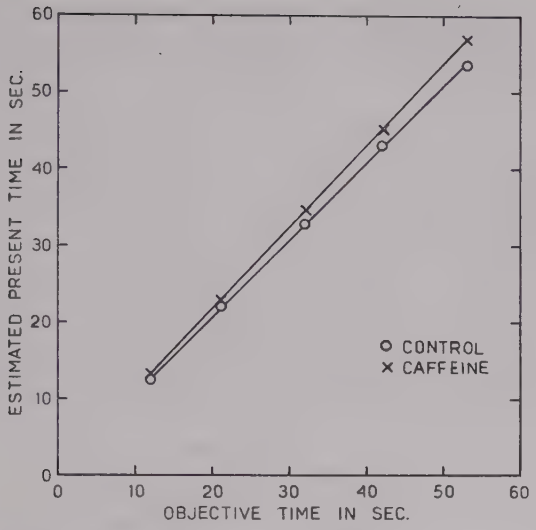

FIG. 9. Present-time estimates after intake of caffeine and lactose placebo (control).

it did not have the expected effect on retained time, and (b) that quinine did not produce any reliable changes in time estimation.

Measures of variability are shown in the Appendix, Tables VII and VIII.

*

The mean scores in *personal tempo* under the three conditions were: control 60.06, quinine 58.21 and caffeine 61.46. None of these small differences reached statistical significance. The largest t-value obtained was 1.040 ($P > 0.10$, $df = 11$) for the difference between quinine and caffeine.

In order to ascertain that the discrepancy between the outcome of this experiment and those by Sterzinger (1935, 1938) and Clauser (1954) was not associated with differences in the technique of drug administration, additional experiments with quinine were carried out on six subjects under conditions more strictly parallel to those employed by the previous investigators. The dose was increased to 660 mg split into two equal doses given with a 2-hour interval. Furthermore the time

between administration of the drug and the experimental session was increased to six hours after the intake of the first dose. However, not even in this case did the estimates obtained under quinine differ from control estimates.

In order to find out if the lack of effect of caffeine on retention of time was due to the dose being too small, some further experiments were carried out. Those eight subjects, who had no subjective symptoms of the 300 mg dose of caffeine were given a dose of 500 mg. In addition to the experiment by the PPT method, a test on retention of word pairs (Cronholm & Molander, 1957) was carried out. The results revealed no influence on retention of time or on retention of word pairs. However, this larger dose produced a pronounced nausea in some subjects. Since, instead of the expected increase in mental alertness, the predominant symptom was nausea accompanied by difficulties in concentration, it is not surprising that facilitating effects on retention failed to appear.

Comment

In the present experiments on time estimation in humans, no parallel was found to the striking effects of quinine on trained feeding habits in ants as observed by Grabensberger (1933). Neither were Sterzinger's conclusions as regards effects of quinine on time estimation in humans supported.

In respect of caffeine the changes produced in present-time estimates were consistent with our previous results with metamphetamine. Thus further support was obtained for Hypothesis II. The prediction concerning effects of caffeine on retained time was not supported by the results.

The subjects seemed relatively unaffected by both drugs judging from introspective accounts and the examiner's observation of their general behaviour. Two subjects reported feelings of drowsiness after intake of 500 mg of quinine and two others experienced ringing in the ears, though the symptoms were not very pronounced. After 300 mg of caffeine four subjects reported feeling agitated or nervous. The majority of subjects, however, was quite free from subjective symptoms. No consistent connection was observed between presence of subjective symptoms and results in the experiment.

When larger doses of the drugs were employed in additional

experiments with some subjects, quinine did not give rise to more pronounced symptoms, whereas caffeine produced nausea in some.

Summary

The influence of quinine and caffeine on time estimation was examined. Previous investigators have claimed that quinine induces marked changes in time estimation, whereas effects produced by caffeine were not considered reliable. The experimental evidence produced so far is, however, not convincing.

The present experiments were performed to determine (a) whether reliable changes in time estimation would occur under the influence of quinine and/or caffeine and (b) if so, what were the characteristics of such changes.

Results obtained by the method of present- and past-time estimation showed that objective seconds were subjectively longer under the influence of caffeine, a result in agreement with Hypothesis II. Quinine, on the other hand, produced no change in time estimation.

Personal tempo did not differ significantly under the three experimental conditions.

Experiment 13: Effects of nitrous oxide

The aim of the present experiment was to study time estimation as influenced by nitrous oxide (N_2O).

In an investigation on effects of nitrous oxide on cognitive behaviour Steinberg (1954) found that performance in cognitive and motor tasks was significantly impaired by a sub-anaesthetic concentration of the drug (30% N_2O in oxygen). During the course of these experiments some subjects spontaneously commented on subjective impressions of changes in time perception. To some subjects time seemed to pass slowly, while others thought that time passed more quickly than usual and a few complained of a complete loss of sense of time. In a subsequent investigation by Steinberg (1955) an attempt was made to

measure these changes by an objective method. The subjects were instructed to count to 30 at an estimated speed of one count per second. No reliable difference was found between the objective time taken to complete the count of thirty under nitrous oxide and under control conditions. The drug induced subjective changes in the rate of passage of time in most subjects, but no relation was found between these subjective changes and changes in estimating seconds by counting.

Burns (1958: personal communication) found that productions of 15-second intervals were markedly longer under the influence of nitrous oxide (20–30% N_2O in oxygen) compared with productions under oxygen. He also found that certain temporal behaviour patterns in cats were significantly changed by nitrous oxide.

The general effects of nitrous oxide in sub-anaesthetic concentrations are similar to those produced by alcohol in small and moderate doses. Under the influence of the drug the subject feels relaxed, carefree and in a pleasant mood. He tends to take less notice of his environment and his susceptibility to stressful situations is diminished (Russell & Steinberg, 1955). The effects do not vary only with the concentration of the drug, but with the same concentration different subjects show different reactions as regards both intensity and type of symptoms. In some subjects drowsiness is a predominant symptom, whereas others become distinctly euphoric and even excited.

Because of these complex and somewhat ambiguous effects on mental alertness (i.e. drowsiness versus excitation), predictions as to effects on perception of time cannot be made with any degree of certainty. It seems likely that if drowsiness combined with a diminished regard for the environment predominates, the effects should be similar to those produced by pentobarbital: the objective second should seem subjectively shorter. If, however, the subject becomes predominantly euphoric, the effects may be reversed. The combined effects of sleepiness and euphoria are not easy to foresee.

With respect to retention of time the effects of nitrous oxide are easier to predict. Whether drowsiness or euphoria pre-

dominates, ability to concentrate should be decreased and memory processes impaired. In line with this, previous investigators have shown learning of nonsense syllables to be impaired (McKinney, 1932; Steinberg & Summerfield, 1957) and memory span to be shortened (Steinberg, 1954) under the influence of sub-anaesthetic concentrations of the drug. Consequently we may expect nitrous oxide to have the same effects on retained time as pentobarbital. It was predicted that scores for retained time would decrease under the influence of nitrous oxide.

Since nitrous oxide is administered in oxygen, time estimates obtained under oxygen breathing were used as control scores. In order to check possible effects of oxygen, time estimates were also obtained when the subject was breathing air.

Procedure

General design.—Twelve subjects participated in the experiment. Each subject came to three sessions and the experimental conditions were rotated according to the following pattern:

Subject	*First session*	*Second session*	*Third session*
1	Air	Nitrous oxide	Oxygen
2	Nitrous oxide	Oxygen	Air
3	Oxygen	Air	Nitrous oxide
4	Air	Oxygen	Nitrous oxide
5	Oxygen	Nitrous oxide	Air
6	Nitrous oxide	Air	Oxygen

etc.

This design was repeated for 12 subjects. The intervals between sessions ranged between a minimum of 1 and maximum of 5 days.

Administration of gases.—A clinical narcosis apparatus (Aga Model MDNB-20) was used for inhalation of a mixture of 30% nitrous oxide and 70% oxygen. This concentration was chosen since it has been shown by Steinberg (1954) to "induce marked changes in most subjects' cognitive behaviour without seriously impairing their cooperativeness". The gas-mixture flowed through the apparatus at a rate of 15 litres per minute and was

delivered via a reservoir bag of 2.5 litres capacity to an oxygen mask with valves to prevent return of used gas. Any surplus escaped through the expiratory valves in the mask. The rate of flow of the gases was measured by flow-meters and, in addition, the oxygen content was continuously checked by a Pauling oxygen analyser connected to the reservoir bag. A microphone was inserted into the mask in order to make communication between experimenter and subject easy. In the control experiments oxygen and air, respectively, were similarly administered and the subjects were not told which they inhaled. (4 subjects received a mixture of 70% oxygen and 30% nitrogen and 8 subjects 100% oxygen.) All gases were scented by inserting into the system a filter-paper impregnated with peppermint oil in order to prevent the subjects from recognizing the gases by smell.

Each experimental session lasted about 40 minutes. The experiment proper was always preceded by 10 minutes of preliminary inhalation, a time period necessary for the physiological effect of nitrous oxide to reach a steady state (Burns, 1958: personal communication).

All subjects were given a preliminary trial with inhalation of nitrous oxide, in order to make them accustomed to the effects of the drug and make it possible to eliminate subjects who might be too much affected to cooperate. (One subject found the effects of the drug disagreeable and was replaced by another.)

Experiments.—In order to standardize the conditions during the preliminary inhalation period the subjects were given some tasks to perform. They were asked to repeat digits forwards and backwards and to count and tap at a subjective speed of 1 per second. The results of these tasks have not been considered.

The subjects were examined by the *PPT method.* Six estimates of each standard duration were obtained for each subject. (One experiment was interrupted because the subject complained of nausea; in this case four estimates instead of six were obtained.) The standard durations used were 12, 21, 32, 42 and 53 seconds.

Personal tempo was examined by the method previously described (see Experiment 5). Each subject had four 30-second trials. The score was the mean number of taps at four 30-second trials, two of which were performed at the beginning and two at the end of each session.

Results

Means of the 12 individual mean scores for present, past and retained time are shown in Table 16.

The table shows (a) that past-time estimates were consistently smaller than the corresponding present-time estimates under all experimental conditions, (b) that present-time estimates were consistently smallest under nitrous oxide and largest under oxygen, (c) that past-time estimates were consistently smallest under nitrous oxide, whereas there was no systematic difference between oxygen and air, and (d) that scores for retained time were also consistently smallest under nitrous oxide, whereas oxygen and air values did not differ systematically. The difference in retained time under nitrous oxide and oxygen is illustrated in Fig. 10.

TABLE 16. *Present, past and retained time under oxygen, nitrous oxide and air.*

Obj. time in sec. ...	12	21	32	42	53
Present time in subj. sec.					
Oxygen	13.89	24.22	35.93	46.93	59.62
Nitrous oxide	12.72	21.85	33.18	44.02	54.92
Air	12.93	22.74	34.10	44.57	55.89
Past time in subj. sec.					
Oxygen	10.01	17.44	24.69	32.50	40.87
Nitrous oxide	8.28	14.12	19.44	26.40	34.55
Air	10.22	16.68	24.56	32.83	38.85
(Past time)/(Present time)					
Oxygen	0.7771	0.7897	0.7487	0.7493	0.7424
Nitrous oxide	0.6639	0.6668	0.6169	0.6390	0.6551
Air	0.8293	0.7672	0.7522	0.7670	0.7354

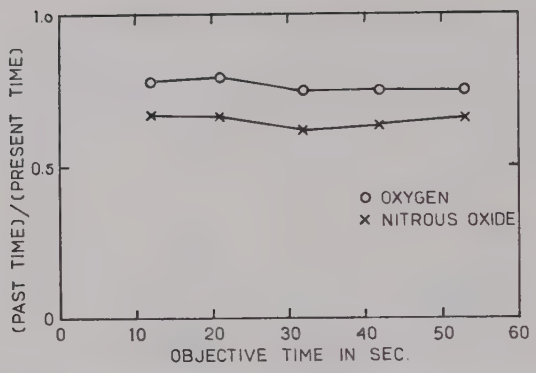

Fig. 10. Quotients for retained time as affected by nitrous oxide.

Total scores for the five standard durations were calculated as before (see Experiment 5) and mean intra-pair differences between scores for present, past and retained time were submitted to *t*-tests. The results are shown in Table 17.

The main comparison is that between nitrous oxide and oxygen. In respect of present time the difference is relatively small and not statistically significant, whereas in respect of past time the difference is highly significant. (Since a directional

TABLE 17. *t-values for intra-pair mean differences under nitrous oxide (N_2O), oxygen (O_2) and air.*

Variable	*t*-value		
	$N_2O - O_2$	N_2O – Air	Air – O_2
Present time	−1.662	−0.567	−1.583
Past time	−3.992	−2.586	−0.345
Retained time	−2.755	−2.475	+0.209

			Two-tailed	One-tailed
$df = 11$;	$P = 0.05$	for $t =$	2.201	1.796
	0.01		3.106	2.718
	0.001		4.437	4.025

prediction for retained time scores was made, the test in this case is one-tailed.) The comparison between nitrous oxide and air shows no difference in present time, but significant differences in past and retained time. Finally, the comparison between air and oxygen shows no significant differences, though the relatively larger *t*-value for present-time estimates (1.583), compared to that obtained for the difference between nitrous oxide and air (0.367), indicates that oxygen may possibly exert an influence on estimation of present time. These effects will be considered below.

The main result is that less was retained of the time perceived under the influence of nitrous oxide. Thus further support was obtained for Hypothesis III.

Measures of variability are shown in the Appendix, Tables IX and X.

*

There were no marked differences in *personal tempo* under the three conditions. The mean scores were: nitrous oxide 47.96, oxygen 49.04 and air 48.02.

Comment

In this experiment it has been possible to measure quantitatively changes in time estimation under the influence of nitrous oxide.

The effects of nitrous oxide on mental state are rather complex. Predominant features, however, are a general carelessness in attitude and impaired concentration. It was argued that these effects would be accompanied by a reduction in the amount of time retained. The results obtained agreed with this prediction.

It could not be predicted how the mixed symptoms of drowsiness and euphoria would affect estimation of present time, which has been shown to be related to amount of mental events. Whereas amount of mental events is decreased in states of drowsiness, it is possibly increased when euphoria predominates. The majority of the 12 subjects in the present experiment showed symptoms of both drowsiness and euphoria. With a larger

number of subjects, and with special attention paid to this question, time estimation as related to inter-individual differences in reactions to the drug could be studied but within the present material this is not possible.

The difference in present-time estimates under nitrous oxide and oxygen was not statistically significant but showed a consistent tendency: estimates were smaller under nitrous oxide than under oxygen. There are three possible interpretations. The differences may be due to chance, they may be due to effects of nitrous oxide or they may be due to effects of oxygen. The fact that present-time estimates were also consistently smaller under air than under oxygen lends some support to the interpretation that oxygen exerted an influence on present time in a direction reverse to that of nitrous oxide.

In the oxygen experiments some subjects remarked that breathing was heavier than usual, a complaint not mentioned under the other conditions. It is possible that this irritation of the respiratory system implied an increase in amount of mental content which, as has been shown in the previous experiments, causes objective seconds to seem subjectively longer.

However, it may be concluded that if oxygen exerted any influence on time estimation, this occurred in a direction reverse to that produced by the nitrous oxide. The four subjects who got 70 per cent oxygen in nitrogen did not differ systematically from those who got pure oxygen. The question remains if there occurs a change in time estimation under the influence of oxygen breathing or if the differences observed were due to chance.

None of the subjects failed to identify nitrous oxide after a few minutes' inhalation. No consistent changes in behavioural or subjective symptoms were noticed as the session progressed. All subjects were able to cooperate satisfactorily, though some had marked difficulties in concentration and had to be repeatedly told to stick to the task. There was no clear relation between type or intensity of the general effects of the drug and effects on time estimates.

Changes in the subjective experience of the rate of passage of time were reported by most subjects, either spontaneously or

upon questioning. None of the subjects thought that time passed slowly under the drug, whereas two subjects remarked on being surprised when the session was over, since time seemed to have passed quickly to them. Most of the subjects stated having considerable difficulties in giving their estimates of past time since "they lost the sense of time" or "did not seem to care about time" or "lost all frames of reference for estimating the time". Present-time estimation was not considered more difficult under the influence of the drug.

The results obtained in the present experiments suggest that subjective impressions of changes in rate of passage of time as observed in this investigation and in the previous investigation by Steinberg (1955) were primarily associated with changes in retention of past time. The same is likely to hold true for the longer productions of 15-second intervals obtained in the experiments by Burns (1958: personal communication).

Summary

Estimation of present and past time in experiments with nitrous oxide (30% N_2O in oxygen), oxygen and air was compared.

It was predicted that scores for retained time would be lower under the influence of nitrous oxide because of impaired memory. The results obtained agreed with this prediction. In respect of present-time estimates, effects of nitrous oxide could not be determined with certainty.

Personal tempo was also examined but no marked differences between the experimental conditions were seen.

CHAPTER X

DISCUSSION

The general assumption that the experience of time is a function of the experience of other events was used as a basis for the formulation of experimental hypotheses concerning certain aspects of time estimation. It was argued that knowledge of the mechanisms governing perception and retention of other events could be utilized for making specific predictions with regard to the perception and retention of time.

The term *perception of time* was restricted to the more or less immediate experience of brief time periods lying within the "conscious present", i.e. time periods grasped as one perceptual unit and hence relatively unaffected by memory factors. (The conscious present may possibly extend over a few seconds; however, in the present investigation estimates of 1-second intervals were chosen for the study of perception of time.) *Retention of time* was studied by measuring the relation between retrospective estimates of longer time intervals (in most experiments between 12 and 53 seconds) and the sum of the 1-second estimates given within this interval.

Studies of time-order errors in other fields of perception and of retention processes in learning experiments provide information concerning the relation generally prevailing between the perception and retention of stimuli: time-order errors are usually negative and the retention of items in learning declines with increasing remoteness from the presentation of stimuli. Since we except time experience to be a function of other experiences, it follows that time percepts should undergo the same sort of change: less should be retained than was perceived.

However, the experimental conditions under which our time estimates were obtained are not analogous to those under which time-order errors and retention are usually measured. Time-order errors are generally studied by presenting two successive stimuli for comparison and varying the time interval between the stimuli and/or the nature of the intervening stimuli. In learning experiments one common procedure is to present a series of stimuli and test the retention of the stimuli at various intervals after their removal. In our experiments on time we presented a series of successive stimuli and examined the retention of the time occupied by these stimuli immediately after the cessation of the stimulus series. What was varied in this case was the length of the stimulus series. Hence our experiments resemble learning experiments, where lists of various lengths are employed. However, retention in learning is usually measured in terms of number of items *correctly* retained, whereas in our case we are only concerned with the *amount* retained of mutually similar stimuli.

It should be emphasized, that though we expect the retention of the amount of external stimulation filling the time interval to be an important determinant of the retention of time, it is certainly not the sole determinant. The time experience will also be influenced by the mental events which accompany the perception of sensory stimuli; in particular, emotional factors will exert a predominant influence. Furthermore, intellectual factors will enter into the estimate, since the subject will usually, to a greater or lesser extent, attempt to correct his estimate on the basis of such cues as are available in the environment and which experience has taught him are helpful for correct time judgments. The inferences to be drawn from these considerations are (a) that we should not expect identity between retention of stimulus material and retention of time, but that the general trend of time estimates may be predicted on the basis of our knowledge of the retention of the stimulus material, and (b) that the question of how to influence the time experience is largely a question of how to influence the cues on which the subject depends for his estimate.

In this connection it should be pointed out that the cues which the subject makes use of are certainly manifold. This implies that as long as we do not radically change the internal or external environment of the subject, we can only expect minor deviations from the "normal" time experience to occur. Examples of effects of drastic changes are seen in certain states of drug intoxication, e.g. hashish and mescaline (see p. 31) and in certain cases of mental illness. In our experiments, however, the variations in external and internal conditions have affected but a few of the cues available and consequently we can expect only minor changes in time estimates.

General support for the assumption that time estimates depend upon the perception and retention of the events filling the time period was derived from experiments showing that the amount of time retained was less than the time perceived and that retention of time followed the same general trend as retention of the amount of stimulus material filling the time interval. Further support was obtained in experiments showing that the relation between time perceived and retained varied with the length of the interval, relatively more being retained of the short intervals, and that it also varied depending upon whether the experimental conditions favoured or impeded retention in general.

Perception of time was studied by examining the conditions which affect the relation between the objective and subjective second. We had the general notion that the internal 1-second standard on which estimates are based is formed by the individual learning to assess the average amount of mental content which corresponds to one clock second. Since this standard is presumably heavily over-learned, it must be expected to be resistant to change. By altering the conditions which ordinarily serve as a frame of reference for the assessment of the amount of mental content which corresponds to one clock second, we should be able to alter the apparent duration of the second. Thus the question to be answered is, what cues does the subject make use of when estimating the amount of mental content? Does he depend upon the intensity of an otherwise constant perception or upon the rate of flow of separate mental events?

The answer derived from experiments was that the rate of flow of events (whether determined by a speeding up or slowing down of mental processes with the aid of drugs or by changes in the number of intermittent stimuli in the external background) will serve to alter the frame of reference on which estimates of 1-second intervals depend.

The preceding discussion indicates that the *amount of change* in the events experienced serves as an important cue for time estimation. It should be noticed, however, that the concept of change enters into the time experience in two different ways. On the one hand, we have an effect on *perception* of time, which is related to the rate of flow of mental events that serves as a frame of reference for the estimate. On the other hand, we have an effect on *retention* of time, which is related to the amount of variety provided by the events filling the time period, more variety serving to increase retention.

Several previous investigators have mentioned the experience of change as an important determinant of experience of time. Fraisse (1957) drew attention to the fact that several of the results obtained in previous investigations on time estimation, particularly those where attitudinal factors operate, may be interpreted in terms of the influence exerted by the amount of change experienced.

In this connection it is interesting to note that Brown (1931) demonstrated a relation between perception of time and movement: "Time where there is movement (filled time) is on the whole phenomenally longer than time marked off by disparate stimuli (unfilled time)". Distortions of perception, as observed in states of hashish and mescaline intoxication, also illustrate the interdependence of experience of time and movement: when, under the influence of the drugs, minutes seem like hours, movements appear extremely slow. Related to these phenomena are the experimental findings by Cohen, Hansel & Sylvester (1955) showing an interdependence between perception of time and distance: when three lights, separated in space, were flashed in succession, the interval between successive flashes seemed longer when the lights were further apart in space.

Finally, it should be pointed out that the problem of inter-individual differences in time estimation may be of considerable interest from the point of view of differential psychology, but that this aspect has not been taken into consideration in the present investigation, where all conclusions are based on group data.

Some speculative remarks

As has been pointed out repeatedly, everyday time experience is a highly complex process which cannot be fully accounted for by such data as may be obtained in a laboratory situation. Nevertheless the same general principles must be at work in everyday life, though often obscured by other factors. Accordingly, we may expect results obtained in the laboratory to contribute to our understanding of the experience of time in real-life situations. In fact, some aspects of everyday time experience seem to fit rather well into the framework of basic principles investigated in this study. A few examples of these aspects will be briefly discussed below.

Waiting for something makes time subjectively long. This is true whether you wait for your dentist or your lover. Our interpretation of this is as follows. There is no particular reason to believe that present time *per se* will be longer, but each time you look at your watch you are surprised to find that your retrospective estimate of the last objective interval is an overestimate: "How is it possible that only three minutes have passed?" This is in line with one of our experiments, where waiting for the time interval to be terminated by an electric shock increased retention of passed time units. It is possible that retention will increase with nearness to the expected termination and that the last few minutes will thus seem particularly long. In everyday time experience this often seems to be the case.

A period of time spent in *passivity* and *monotony* usually seems long in passing, for example during a period of convalescence. The above interpretation of extension of time spent in waiting seems to account for this phenomenon as well. One has nothing to do but wait for the next of the few things that happen,

the next meal or the arrival of the mail. Accordingly, one is highly aware of the passage of time and this, as we have seen, is likely to increase retention of time.

The same monotonous, passively spent time period usually seems *short in retrospect*, years later. This, too, may be explained in terms of retention. In a subsequent, active state of life, the events filling the period of convalescence are highly trivial, not worthwhile remembering. The past passive period of time is rapidly fading in memory and years later it may seem almost lost.

In contrast, a time period filled with *varied activities* often seems *short as long as it lasts*. The objective second may be subjectively long under such conditions, but one does not consult one's watch each second. One is engaged in activity rather than time, and hence the awareness of passing time is decreased.

This same period filled with changing activity is *long in retrospect*. It was full of events which were and still may be important, i.e. closely related to personal motivation. Afterwards, then, the events will be well remembered as compared with the trivial things of convalescence.

The apparent acceleration of time with age may be interpreted in terms of amount of change, which, as we have seen, has proved a useful concept in explanations of subjective time. This may be illustrated by a quotation from James (1890, p. 625): "In youth we may have an absolutely new experience, subjective or objective, every hour of the day. Apprehension is vivid, retentiveness strong, and our recollections of that time ... are of something intricate, multitudinous, and long-drawn-out. But as each passing year converts some of this experience into automatic routine which we hardly note at all, the days and the weeks smooth themselves out in recollection to countless units, and the years grow hollow and collapse."

The relation between time experience and age may also be considered from the point of view of retention. As we have seen, the retrospective experience of time periods of various lengths bears certain resemblances to the learning of lists of various lengths: the relative retention of a list decreases with increasing

length of the list and the same principle has been shown to be valid for time estimates within our experimental range. Let us, for the purpose of illustration, consider the years of our life already passed as analogous to a list of events in a life-long learning experiment. If the same principle continues to hold true, it is to be expected that *each year will add less* to the overall experience of our total past life. This is certainly what happens to everyone.

Much of everyday time experience seems paradoxical. Time may, as it is sometimes phrased, seem both long and short at the same "time". This is probably in part a consequence of confusion between the fundamental aspects of present and past time. It is probably also a consequence of confusion between various aspects of past time: retention may be good *within* a passing period and poor in a subsequent period of life, as in the case of convalescence and later active life. Some of the paradoxes are certainly also related to effects of emotional factors which we have refrained from studying in this investigation. Such factors are also likely to throw additional light on the examples of everyday time experience which have been discussed above.

CHAPTER XI

GENERAL SUMMARY

The aim of the present investigation was to examine some special problems of subjective time: the relation between perception and retention of time and the mode in which these two aspects of the time experience may be influenced by certain changes in the experimental conditions.

The term *perception of time* was restricted to the experience of brief time intervals which may be grasped as one perceptual unit and hence may be assumed to be relatively unaffected by memory factors. Estimates of such short time intervals were termed *present-time estimates.*

The term *retention of time* was used to denote the experience in retrospect of longer time intervals, which could be assumed to be influenced by memory factors. Such retrospective estimates were termed *past-time estimates.* By calculating the quotient (past time)/(present time) *scores for retained time* were obtained.

Essentially the work was based on the assumption that the time experience is a function of the experience of other events rather than mediated by some special "time sense". Hence it should be possible to make certain predictions with regard to the time experience on the basis of what is known of the perception and retention of the events filling the time period. It is true that experience of time is not solely dependent upon the perception and retention of sensory stimuli, but is readily influenced by other mental processes, e.g. emotional and attitudinal factors, which are difficult to control. If, however, the influence of such factors can be kept under control or at least

decreased, it should be possible to make directional predictions concerning the time experience.

As a background for the present experimental approach, similarities and dissimilarities between measurement of retention of time, on the one hand, and measurement of retention in learning experiments and of time-order errors in perception, on the other, were discussed. It could be inferred that retrospective estimates of time would show evidence of "forgetting" due to a fading of brain traces, as manifested by retention loss in learning, and negative time-order errors in perception. This inference, the essence of which is that the time retained would be less than the time perceived, served as a starting point for the formulation of our problems and hypotheses.

Problems and hypotheses

The first problem concerns the *relation between time perceived and time retained.* On the basis of the above considerations it was assumed that the relation between time perceived and retained would be analogous to the relation between perception and retention of the mental events filling the time period. However, retention of past time is associated with *amount* retained and does not imply a correct retention of details, as is generally the case in respect of retention of learned material. Because amount retained is usually less than amount perceived, it was predicted that the estimate of an elapsed time period would be smaller than the sum of the present-time estimates on which it is based (Hypothesis I).

The second problem concerns *conditions influencing perception of time* as measured by determining the relation between the objective and subjective second. It was argued that the internal 1-second standard on which the subject bases his estimate has been established by the individual learning to assess the amount of mental content which (on an average) corresponds to the objective second. Hence a change in amount of mental content per objective time unit, as brought about by drug-induced variations in mental alertness or by variations in amount of external stimulation, should alter the apparent duration of the second.

It was predicted that an increase in amount of mental content would make the objective second seem subjectively longer, whereas a decrease would have the reverse effect (Hypothesis II).

The third problem concerns *conditions affecting retention of time.* Since we expect retention of time to be related to the retention of the events which occupy the time period, we also expect conditions which influence the retention of these other processes (such as mental alertness, attention, similarity between stimuli) to affect retention of time in a similar way. It was predicted that more would be retained of the time units perceived within a given interval under conditions which favour retention than under conditions which impede retention (Hypothesis III).

Experiments

A method, denoted the *method of estimation of present and past time*, was devised which made possible combined measurements of perception and retention of time. Essentially the method consists in having the subject name randomized digits at an estimated rate of 1 per second (present-time estimates) for a given period of time, and to estimate in retrospect the length of this period (past-time estimate). The quotient (past time)/(present time) gives a measure of retained time.

The relation between perception and retention of time and of sensory stimuli was examined in Experiments 1 to 4. It was shown that estimates of past time were consistently smaller than the present-time estimates on which they were based, i.e. the amount retained was less than the amount perceived. The discrepancy between time perceived and retained increased with increasing length of time interval, reaching a relatively stable level at intervals of about 20 seconds. Furthermore a close correspondence was found between amount of time retained and number of stimuli retained. These results were in full agreement with Hypothesis I. Further support for the hypothesis was obtained in Experiments 5, 6, 8, 10, 12 and 13.

Perception and retention of time as affected by variations in internal conditions was examined in Experiment 5. The degree

of mental alertness was varied by the use of metamphetamine, pentobarbital and a lactose placebo. It was assumed that variations in mental alertness would be accompanied by variations in amount of mental content per objective time unit and by variations in memory processes. Accordingly it was predicted that both perception and retention of time would be affected by the drugs; the objective second should seem subjectively shorter and less should be retained of the seconds perceived under the influence of pentobarbital than under metamphetamine. The results obtained agreed with the predictions and thus supported Hypotheses II and III.

Perception of time as influenced by variations in external stimulus conditions was examined in Experiments 6 to 9. The question to be answered was, what are the external cues a subject makes use of when assessing the amount of mental content, which he believes to correspond to one objective second: the perceived rate of separate events and/or the perceived intensity of one and the same stimulus. The problem was approached by studying the effects of *amount of change* in the stimulus background as provided by intermittent auditory stimuli and the effects of *intensity* of an otherwise constant auditory stimulus. It was shown that the objective second was subjectively longer when the amount of change was increased, whereas no effect of the intensity of the background stimulus was seen. Effects of intensity were studied further by varying the intensity of the stimulus content as distinct from the stimulus background. Not even in this case did the intensity have any marked effect on the apparent duration of the second. It was concluded that the rate of flow of mental events does influence the perception of time, whereas no support was obtained for the assumption that the intensity of a constant stimulus would affect time perception. These results are in good agreement with those obtained by drug-induced changes in mental alertness, in which case the effects on perception of time were presumably related to changes in the rate of flow of mental events. This implies that we are now able to substitute the broad concept "amount of mental content" as used in Hypothesis II by the more restricted concept "rate of

flow of mental events" and we may conclude that the results obtained by variations in external factors are in general agreement with Hypothesis II.

Retention of time as influenced by variations in external conditions was studied in Experiments 10 and 11. The aim was to examine retention of time as influenced by such external conditions as could be assumed to improve or impair retention of the events filling the time period. Time estimates obtained under conditions of increased attention, as brought about by the application of an electric shock at the termination of each time interval, were compared with estimates obtained under control conditions. It was argued that anticipation of the shock would cause the time units in passing to be more acutely memorized and thus favour retention of past time. The results agreed with the prediction based on Hypothesis III in showing that more was retained of the elapsed time period under shock conditions than under control conditions.

Time estimation was also studied under conditions providing various degrees of similarity between successive events filling the time period. Since a high degree of similarity between successive events is known to have a detrimental effect on learning processes, it was predicted that a time period would seem shorter in retrospect when filled with one type of activity only than when filled with two types. The results obtained agreed with the prediction and thus supported Hypothesis III in showing that more was retained of the time experienced under conditions which favoured retention.

Time estimation as affected by quinine and caffeine was examined in Experiment 12. Previous investigators had claimed that quinine induced marked changes in time estimation, whereas effects produced by caffeine were not considered reliable. Results obtained in the present experiment indicated an influence of caffeine on the perception of time: the objective second was subjectively longer after intake of caffeine. This result may be interpreted in terms of an increase in the rate of flow of mental events as brought about by caffeine. Quinine, on the other hand, had no noticeable influence on time estimation.

Time estimation as affected by nitrous oxide in sub-anaesthetic doses was examined in Experiment 13. Previous investigators had reported subjective changes in time experience under the influence of the drug, whereas experiments had failed to verify effects on the estimation of seconds by counting. Other experiments showed that changes could be recorded objectively by the method of production. However, the question of which aspect of the time experience was affected by nitrous oxide had not been answered. The present experiment showed that the primary effect was on retention of time, less being retained of an elapsed time period under the influence of the drug. In respect of perception of time, possible effects of nitrous oxide could not be determined with certainty.

APPENDIX

TABLE I. *Inter-individual differences in present, past and retained time; S.D. = standard deviation, V = coefficient of variation. (Expt. 1)*

Obj. time in sec. ...	12	21	32	42	53
Present time					
S.D.	2.66	4.52	6.66	8.88	10.81
V	21.26	20.69	20.37	20.71	20.25
Past time					
S.D.	2.60	4.28	5.48	7.80	10.07
V	26.91	26.00	23.56	25.62	25.71
Retained time					
S.D.	0.212	0.211	0.192	0.183	0.196
V	26.76	27.35	26.34	25.38	26.17

TABLE II. *Intra-individual variability in present and past time. (Expt. 1)*

Obj. time in sec. ...	12	21	32	42	53
Present time					
S.D.	0.92	1.40	2.02	2.31	3.36
V	7.37	6.40	6.16	5.39	6.28
Past time					
S.D.	1.81	3.34	4.35	5.34	6.12
V	18.68	20.29	18.71	17.55	15.62

TABLE III. *Inter-individual differences in present, past and retained time after intake of pentobarbital and metamphetamine. (Expt. 5)*

Obj. time in sec. ...	12	21	32	42	53
Present time S.D.					
Pentobarb.	2.92	4.92	7.20	10.13	12.62
Metamph.	3.15	5.37	8.10	10.99	13.91
Present time V					
Pentobarb.	23.87	23.31	22.84	24.73	24.65
Metamph.	24.16	23.47	23.77	24.58	24.90
Past time S.D.					
Pentobarb.	2.20	3.78	6.33	7.86	9.29
Metamph.	2.09	4.45	5.80	7.24	8.58
Past time V					
Pentobarb.	25.51	27.25	29.85	27.70	26.47
Metamph.	20.91	25.55	23.57	22.46	22.13
Retained time S.D.					
Pentobarb.	0.203	0.191	0.195	0.177	0.187
Metamph.	0.209	0.212	0.212	0.213	0.199
Retained time V					
Pentobarb.	28.10	28.22	28.30	25.04	26.44
Metamph.	26.27	26.80	28.30	28.36	27.59

TABLE IV. *Intra-individual variability in present and past time after intake of pentobarbital and metamphetamine. (Expt. 5)*

Obj. time in sec. ...	12	21	32	42	53
Present time S.D.					
Pentobarb.	0.91	1.20	1.82	2.26	2.67
Metamph.	0.88	1.18	1.83	1.82	2.42
Present time V					
Pentobarb.	7.45	5.68	5.78	5.51	5.21
Metamph.	6.75	5.16	5.36	4.06	4.34
Past time S.D.					
Pentobarb.	1.84	3.01	4.30	4.81	5.94
Metamph.	1.99	3.87	4.12	6.01	6.34
Past time V					
Pentobarb.	21.29	21.70	20.27	16.93	16.93
Metamph.	19.85	22.20	16.76	18.65	16.35

TABLE V. *Inter-individual differences in present, past and retained time under electric shock and control conditions. (Expt. 10)*

Obj. time in sec. ...	13	25	41	55	72
Present time S.D.					
Shock	3.13	5.99	9.21	11.62	16.26
Control	3.39	6.07	8.79	12.91	14.79
Present time V					
Shock	29.09	29.57	27.71	26.51	28.28
Control	30.62	29.33	26.51	28.89	25.11
Past time S.D.					
Shock	2.94	6.47	7.75	13.00	16.95
Control	2.69	4.02	4.67	6.66	10.18
Past time V					
Shock	28.73	35.26	27.74	34.91	32.91
Control	30.52	25.20	18.20	19.54	22.88
Retained time S.D.					
Shock	0.221	0.244	0.289	0.324	0.319
Control	0.115	0.186	0.225	0.234	0.289
Retained time V					
Shock	22.55	26.07	32.53	36.20	33.76
Control	14.40	23.27	27.47	28.61	35.71

TABLE VI. *Intra-individual variability in present and past time under electric shock and control conditions. (Expt. 10)*

Obj. time in sec. ...	13	25	41	55	72
Present time S.D.					
Shock	1.06	1.65	3.14	3.74	3.99
Control	1.09	1.51	2.91	3.83	5.08
Present time V					
Shock	9.81	8.17	9.44	8.54	6.94
Control	9.83	7.30	8.79	8.56	8.63
Past time S.D.					
Shock	2.02	3.35	5.66	8.14	8.87
Control	1.70	3.11	7.63	7.70	10.96
Past time V					
Shock	19.79	18.25	20.25	21.84	17.22
Control	19.26	19.51	29.75	22.59	24.64

TABLE VII. *Inter-individual differences in present and past time under control, quinine and caffeine conditions. (Expt. 12)*

Obj. time in sec. ...	12	21	32	42	53
Present time S.D.					
Control	3.70	6.99	9.59	12.90	16.32
Quinine	3.83	6.99	10.64	13.85	17.58
Caffeine	3.58	6.29	9.22	12.02	15.25
Present time V					
Control	29.39	31.70	29.22	29.84	30.32
Quinine	30.30	32.19	32.39	32.27	32.76
Caffeine	29.96	27.21	26.47	26.46	26.88
Past time S.D.					
Control	2.98	5.09	8.14	10.77	13.77
Quinine	2.05	3.47	7.02	9.60	13.45
Caffeine	2.55	4.16	6.11	9.36	12.73
Past time V					
Control	34.52	34.44	37.81	37.92	38.41
Quinine	22.98	25.53	32.20	34.86	36.83
Caffeine	28.21	28.72	27.94	31.83	33.80
Retained time S.D.					
Control	0.230	0.231	0.229	0.244	0.252
Quinine	0.230	0.235	0.264	0.251	0.322
Caffeine	0.222	0.208	0.205	0.240	0.303
Retained time V					
Control	32.17	32.91	33.63	35.36	36.10
Quinine	30.42	34.61	36.97	36.64	43.51
Caffeine	30.96	31.56	31.16	35.35	42.92

TABLE VIII. *Intra-individual variability in present and past time under control, quinine and caffeine conditions. (Expt. 12)*

Obj. time in sec. ...	12	21	32	42	53
Present time S.D.					
Control	0.91	1.59	2.47	3.12	3.38
Quinine	1.12	1.43	2.22	2.53	3.40
Caffeine	1.20	1.75	2.23	2.96	3.47
Present time V					
Control	7.22	7.22	7.52	7.21	6.29
Quinine	8.86	6.56	6.77	5.89	6.34
Caffeine	9.03	7.56	6.39	6.51	6.11

(Cont. Table VIII.)

Obj. time in sec. ...	12	21	32	42	53
Past time S.D.					
Control	1.70	3.05	5.10	6.91	7.26
Quinine	2.08	3.15	4.29	6.22	5.51
Caffeine	1.54	3.12	4.36	5.92	5.82
Past time V					
Control	19.70	20.59	23.70	24.34	20.26
Quinine	23.27	23.17	19.65	22.58	15.09
Caffeine	16.98	21.55	19.95	20.11	15.46

TABLE IX. *Inter-individual differences in present, past and retained time under oxygen, nitrous oxide and air. (Expt. 13)*

Obj. time in sec. ...	12	21	32	42	53
Present time S.D.					
Oxygen	4.64	8.51	12.00	15.30	20.12
Nitrous oxide	3.33	6.04	9.50	12.75	16.72
Air	3.87	6.49	9.69	12.69	15.63
Present time V					
Oxygen	33.38	35.13	33.41	32.60	33.75
Nitrous oxide	26.16	27.62	28.63	28.96	30.45
Air	29.93	28.55	28.43	28.47	27.96
Past time S.D.					
Oxygen	2.70	5.42	7.27	9.24	10.38
Nitrous oxide	2.86	5.44	7.02	7.73	12.18
Air	3.11	5.10	7.26	10.25	11.27
Past time S.D.					
Oxygen	26.92	31.08	29.44	28.43	25.40
Nitrous oxide	34.54	38.53	36.08	29.27	35.26
Air	30.42	30.60	29.58	31.22	29.02
Retained time S.D.					
Oxygen	0.242	0.284	0.272	0.264	0.240
Nitrous oxide	0.166	0.210	0.218	0.205	0.190
Air	0.236	0.224	0.226	0.217	0.237
Retained time V					
Oxygen	31.15	36.01	36.44	35.31	32.41
Nitrous oxide	25.06	31.52	35.48	35.48	29.00
Air	28.46	29.20	30.09	28.38	32.32

TABLE X. *Intra-individual variability in present and past time under oxygen, nitrous oxide and air. (Expt. 13)*

Obj. time in sec. ...	12	21	32	42	53
Present time S.D.					
Oxygen	0.94	1.38	2.24	2.68	2.88
Nitrous oxide	1.21	1.86	2.95	4.22	3.64
Air	1.06	1.35	2.19	2.69	3.74
Present time V					
Oxygen	6.74	5.70	6.24	5.70	4.83
Nitrous oxide	9.52	8.52	8.88	9.58	6.63
Air	8.21	5.95	6.43	6.04	6.70
Past time S.D.					
Oxygen	2.21	3.52	4.44	5.54	8.43
Nitrous oxide	1.74	3.14	5.18	5.44	8.33
Air	2.37	3.11	4.42	6.78	7.09
Past time V					
Oxygen	22.06	20.19	17.97	17.04	20.62
Nitrous oxide	21.06	22.27	26.65	20.60	24.10
Air	23.19	18.65	18.00	20.64	18.25

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